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Work Plan for a Demonstration of Remediation by Natural Attenuation for Groundwater at Sites FTA 2 and Area A

AF CENTER FOR ENVIRONMENTAL EXCELLENCE

Tinker Air Force Base
Oklahoma City, Oklahoma

Prepared For

Air Force Center for Environmental Excellence
Technology Transfer Division
Brooks Air Force Base
San Antonio, Texas

and

Tinker Air Force Base
Oklahoma City, Oklahoma

March 1997

PARSONS
ENGINEERING SCIENCE, INC.

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WORK PLAN FOR A TREATABILITY STUDY IN SUPPORT OF REMEDIATION BY NATURAL ATTENUATION AT SITES FTA 2 AND AREA A

at

TINKER AIR FORCE BASE

OKLAHOMA CITY, OKLAHOMA

February 1997

Prepared for:

AIR FORCE CENTER FOR ENVIRONMENTAL EXCELLENCE

TECHNOLOGY TRANSFER DIVISION

BROOKS AIR FORCE BASE

SAN ANTONIO, TEXAS

AND

TINKER AIR FORCE BASE

OKLAHOMA CITY, OKLAHOMA

Prepared by:

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1700 Broadway, Suite 900

Denver, Colorado 80290

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ACRONYMS AND ABBREVIATIONS

AFB	Air Force Base
AFCEE	Air Force Center for Environmental Excellence
AOC	Area of Concern
Area A	Area of Concern "A" (Base Service Station)
bgs	below ground surface
BTEX	benzene, toluene, ethylbenzene, and xylene
°C	degrees Celsius
CAH	chlorinated aliphatic hydrocarbon
CFR	Code of Federal Regulations
CO_2	carbon dioxide
DCA	dichloroethane
DCE	dichloroethene
DO	dissolved oxygen
DOD	Department of Defense
ERI	Environmental Recovery, Inc.
ft/ft	feet per foot
FTA 2	Fire Training Area 2
GWTP	groundwater treatment plant
HDPE	high density polyethylene
HSA	hollow-stem auger
HWBZ	Hennessey water-bearing zone
ID	inside diameter
IT	IT Corporation
IRP	Installation Restoration Program
IWTP	industrial wastewater treatment plant
K	hydraulic conductivity
LCS	laboratory control sample

LMB	laboratory method blank
LNAPL	light non-aqueous phase liquid
LSZ	lower saturated zone
LTM	long-term monitoring
μg/kg	micrograms per kilogram
μg/L	micrograms per liter
mg/L	milligrams per liter
MSDS	material data safety sheets
msl	mean sea level
NGVD	National Geodetic Vertical Datum
NRMRL	National Risk Management Research Laboratory
OAC	Oklahoma Administrative Code
OD	outside diameter
ORD	USEPA Office of Research and Development
ORP	oxidation reduction potential
OSWER	USEPA Office of Solid Waste and Emergency Response
OVM	organic vapor meter
PA	preliminary assessment
PAH	polynuclear aromatic hydrocarbon
Parsons ES	Parsons Engineering Science, Inc.
PCB	polychlorinated biphenyl
PCE	tetrachloroethene
POC	point of contact
ppmv	parts per million, volume by volume
PVC	polyvinyl chloride
QA	quality assurance
QC	quality control
RAP	remedial action plan
RCRA	Resource Conservation and Recovery Act
redox	reduction/oxidation

RFI	RCRA Facility Investigation
RNA	remediation by natural attenuation
SI	site inspection
SVOC	semivolatile organic compound
SWMU	solid waste management unit
T	transmissivity
TCA	trichloroethane
TCE	trichloroethene
TCLP	toxicity characteristics leaching procedure
TOC	total organic carbon
TPH	total petroleum hydrocarbons
TS	Treatability Study
TT	Tetra Tech, Inc.
USACE	United States Army Corps of Engineer
USEPA	US Environmental Protection Agency
UST	Underground Storage Tank
USZ	upper saturated zone
VC	vinyl chloride
VOC	volatile organic compound
WSCI	Water and Soil Consultants, Inc.

SECTION 1

INTRODUCTION

This work plan, prepared by Parsons Engineering Science, Inc. (Parsons ES), presents the scope of work required for the collection of data necessary to conduct a treatability study (TS) for groundwater contaminated with chlorinated aliphatic hydrocarbons (CAHs) and benzene, toluene, ethylbenzene, and xylenes (BTEX) at two sites located at Tinker Air Force Base (AFB), in Oklahoma City, Oklahoma (the Base). The two sites to be investigated are Fire Training Area 2 (FTA 2), and the former Base service station (Area A). Hydrogeologic and groundwater chemical data collected under this program can also be used to evaluate various engineered remedial options; however, this work plan is oriented toward the collection of hydrogeologic data to be used in support of remediation by natural attenuation (RNA) with long-term monitoring (LTM) for restoration of groundwater contaminated with CAHs and BTEX.

As used in this report, RNA refers to a management strategy that relies on natural attenuation mechanisms to remediate contaminants dissolved in groundwater and to control receptor exposure risks associated with contaminants in the subsurface. The United States Environmental Protection Agency (USEPA) Offices of Research and Development (ORD) and Solid Waste and Emergency Response (OSWER) have proposed the following definition of natural attenuation (Wilson, 1996):

> *The biodegradation, dispersion, sorption, volatilization, and/or chemical and biochemical stabilization of contaminants to effectively reduce contaminant toxicity, mobility, or volume to levels that are protective of human health and the ecosystem.*

As suggested by this definition, mechanisms for natural attenuation of CAHs and BTEX include advection, dispersion, dilution from recharge, sorption, volatilization, and biodegradation. Of these processes, biodegradation is the primary mechanism working to transform contaminants into innocuous byproducts. Contaminant destruction occurs through natural attenuation when indigenous microorganisms work to bring about a reduction in the total mass of contamination in the subsurface without the addition of nutrients. Patterns and rates of natural attenuation can vary markedly from site to site depending on governing physical and chemical processes.

RNA is advantageous for the following reasons:

- Contaminants can ultimately be transformed to innocuous byproducts (e.g., carbon dioxide, ethene, or water), not just transferred to another phase or location within the environment;
- Current pump-and-treat technologies are energy intensive and generally not effective in reducing residual contamination;
- The process is nonintrusive and allows continuing use of infrastructure during remediation;
- Current engineered remedial technologies may pose a greater risk to potential receptors than RNA (e.g., contaminants may be transferred into another medium during remediation activities); and
- RNA is less costly than conventional, engineered remedial technologies.

The disadvantages of RNA include the following:

- Contaminants considered to be more mobile and toxic can be produced as byproducts of biodegradation [e.g., vinyl chloride (VC)];

- The effectiveness of RNA is generally limited by site geochemistry and the availability of substrates; and
- RNA frequently takes longer to reach specified concentration limits than other remedial alternatives.

This work plan was developed on the basis of discussions among representatives from Tinker AFB, the Air Force Center for Environmental Excellence (AFCEE), the USEPA National Risk Management Research Laboratory (NRMRL), and Parsons ES. These discussions included a roundtable meeting attended by representatives of these four organizations at Tinker AFB on November 21, 1996, to discuss candidate sites and a specific approach for this RNA evaluation. In addition, available site characterization data were reviewed during the preparation of this work plan. All field work will follow the health and safety procedures presented in the *Program Health and Safety Plan for the Demonstration of Remediation by Natural Attenuation* (Parsons ES, 1996) and the site-specific addendum to the program Health and Safety Plan (Parsons ES, 1997). This work plan was prepared for AFCEE and Tinker AFB.

1.1 SCOPE OF CURRENT WORK PLAN

This project is part of a large, broad-based initiative being conducted by AFCEE in conjunction with the NRMRL and Parsons ES. The intent of the RNA demonstration program is to develop a systematic process for scientifically investigating and documenting natural, subsurface chemical attenuation processes that can be factored into overall site remediation plans (Wiedemeier *et al.*, 1996a). For this reason, the work described in this work plan is directed toward the collection of data in support of demonstrating the effectiveness of RNA of CAHs and BTEX in groundwater. Data required to develop alternative remedial strategies, should RNA prove not to be a viable groundwater remedial option at one or both of these sites, also will be collected under this program. A secondary goal of this multi-site initiative is to provide a

database from multiple sites that demonstrates that natural processes of contaminant degradation often can reduce contaminant concentrations in groundwater to below acceptable cleanup standards before potential receptor exposure pathways are complete.

The specific objective for the demonstration at site FTA 2 is to investigate the degree to which CAHs dissolved in groundwater are being remediated through natural attenuation so that this information can be used by Tinker AFB to develop an effective groundwater remediation strategy. The specific objective for the demonstration at site Area A is to investigate the degree to which both CAHs and BTEX dissolved in groundwater are being remediated through natural attenuation in order to develop an effective groundwater remediation strategy. These demonstrations are not necessarily intended to fulfill specific federal or state requirements regarding site assessments, remedial action plans (RAPs), or other such mandated investigations and reports.

This work plan describes the site characterization activities to be performed by personnel from Parsons ES, the U.S. Army Corps of Engineers (USACE), and the Subsurface Protection and Remediation Division of the NRMRL (formerly the USEPA's Robert S. Kerr Environmental Research Laboratory) in support of the TS. Field activities will be performed to collect data for evaluating the effectiveness of RNA in remediating the dissolved CAH and BTEX plumes at Sites FTA 2 and Area A. The data collected during the TS will be used along with data from previous investigations to characterize contaminant and geochemical patterns at the site, and as input for analytical groundwater flow and solute transport models to make predictions of the future concentrations and extent of contamination.

Site characterization activities in support of the demonstration will include:

- Determination of preferential contaminant migration and potential receptor exposure pathways;

- Soil sample collection using hollow-stem auger drilling or Geoprobe® direct-push technology;
- Groundwater monitoring well or monitoring point installation using hollow-stem or mud-rotary drilling, or the Geoprobe®;
- Groundwater sample collection from newly installed monitoring wells or points, and existing monitoring wells;
- Soil and groundwater sample analysis; and
- Aquifer testing.

The materials and methodologies to accomplish these activities are described in Section 3.

The contaminant fate and transport modeling effort has three primary objectives: 1) predict the future extent and concentration of dissolved contaminant plumes by modeling the effects of advection, dispersion, sorption, and biodegradation; 2) assess the possible exposure of potential downgradient receptors to contaminant concentrations that exceed levels intended to be protective of human health and the environment; and 3) provide technical support for selection of RNA as a component of site remediation at regulatory negotiations, as appropriate.

Previously reported site-specific data and data collected during the supplemental site characterization activities described in this work plan will be used as input for the groundwater flow and solute transport models. Where site-specific data are not available, conservative parameter values for the types of aquifer materials present at the site will be obtained from widely accepted, published literature and used for model input. Sensitivity analyses will be conducted for the parameters that are known to have the greatest influence on the model results, and where possible, the models will be

calibrated using historical site data. If it is shown that RNA by itself is not the most appropriate remedial option, Parsons ES will recommend an appropriate groundwater remedial technology on the basis of available data.

This work plan consists of six sections, including this introduction. Section 2 presents a review of available, previously-reported, site-specific data and conceptual models for FTA 2 and Area A. Section 3 describes the proposed sampling strategy and procedures to be used for the collection of additional site characterization data. Section 4 describes the quality assurance/quality control (QA/QC) measures to be used during this project. Section 5 describes the remedial option evaluation procedure and report format. Section 6 contains the references used in preparing this document. There are four appendices to this work plan. Appendix A contains a listing of containers, preservatives, packaging, and shipping requirements for soil and groundwater analytical samples. Appendices B and C contain supplemental site data, including summarized groundwater elevation data and figures, analytical results, and geologic boring logs and monitoring well construction diagrams for Sites FTA 2 and Area A, respectively. Tinker AFB well installation standards are presented in Appendix D.

1.2 BACKGROUND

Tinker AFB is in central Oklahoma, in the southeastern portion of Oklahoma County (Figure 1.1). Tinker AFB covers approximately 5,000 acres the southeastern Oklahoma City metropolitan area. Tinker AFB was originally known as the Midwest Air Depot and began operations in July 1941. The Base was formally activated in March 1942 and serves as an international repair depot for a variety of aircraft, weapons, and engines.

Tinker AFB currently operates under a Resource Conservation Recovery Act (RCRA) Hazardous Waste Management Permit issued by the USEPA (July 1, 1991). This permit requires Tinker AFB to investigate all solid waste management units

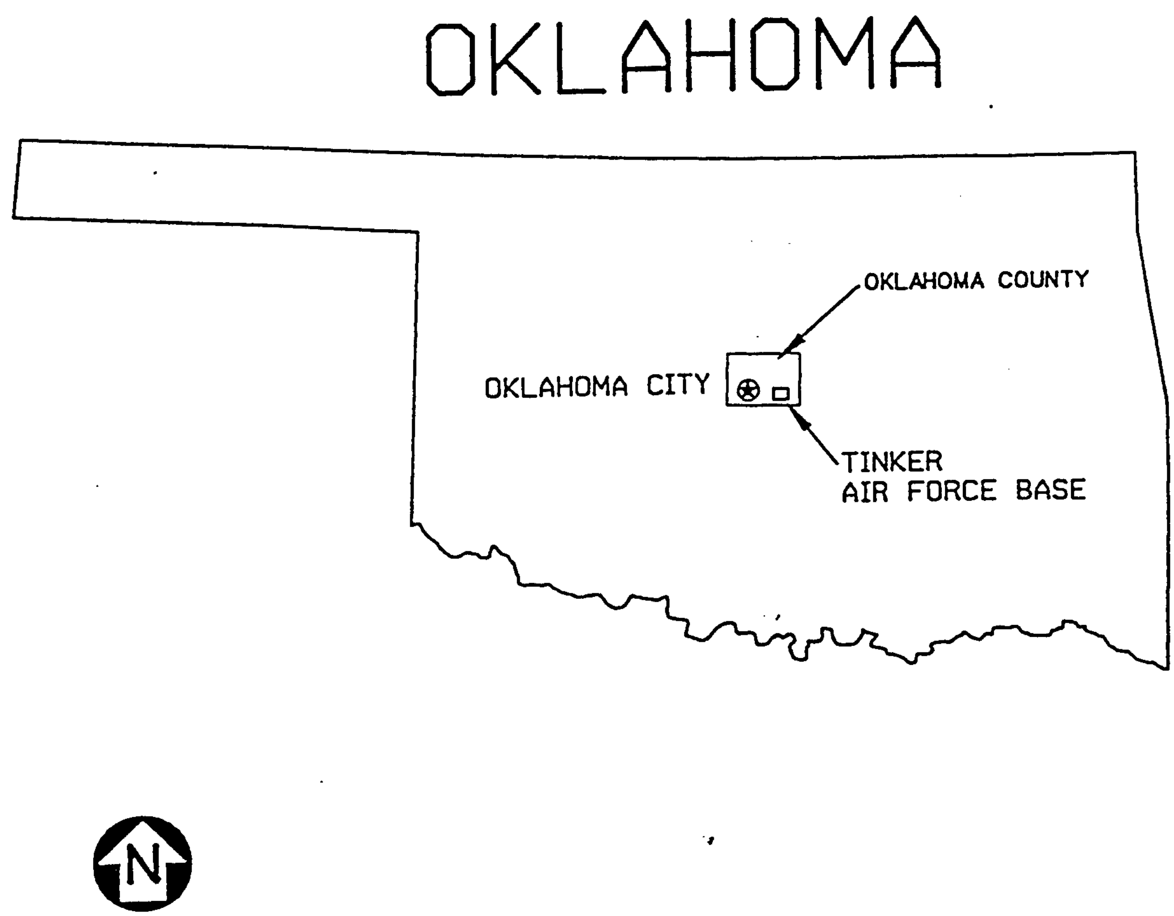

FIGURE 1.1

LOCATION OF TINKER AIR FORCE BASE

Sites FTA 2 and Area A
RNA TS
Tinker AFB, Oklahoma

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Denver, Colorado

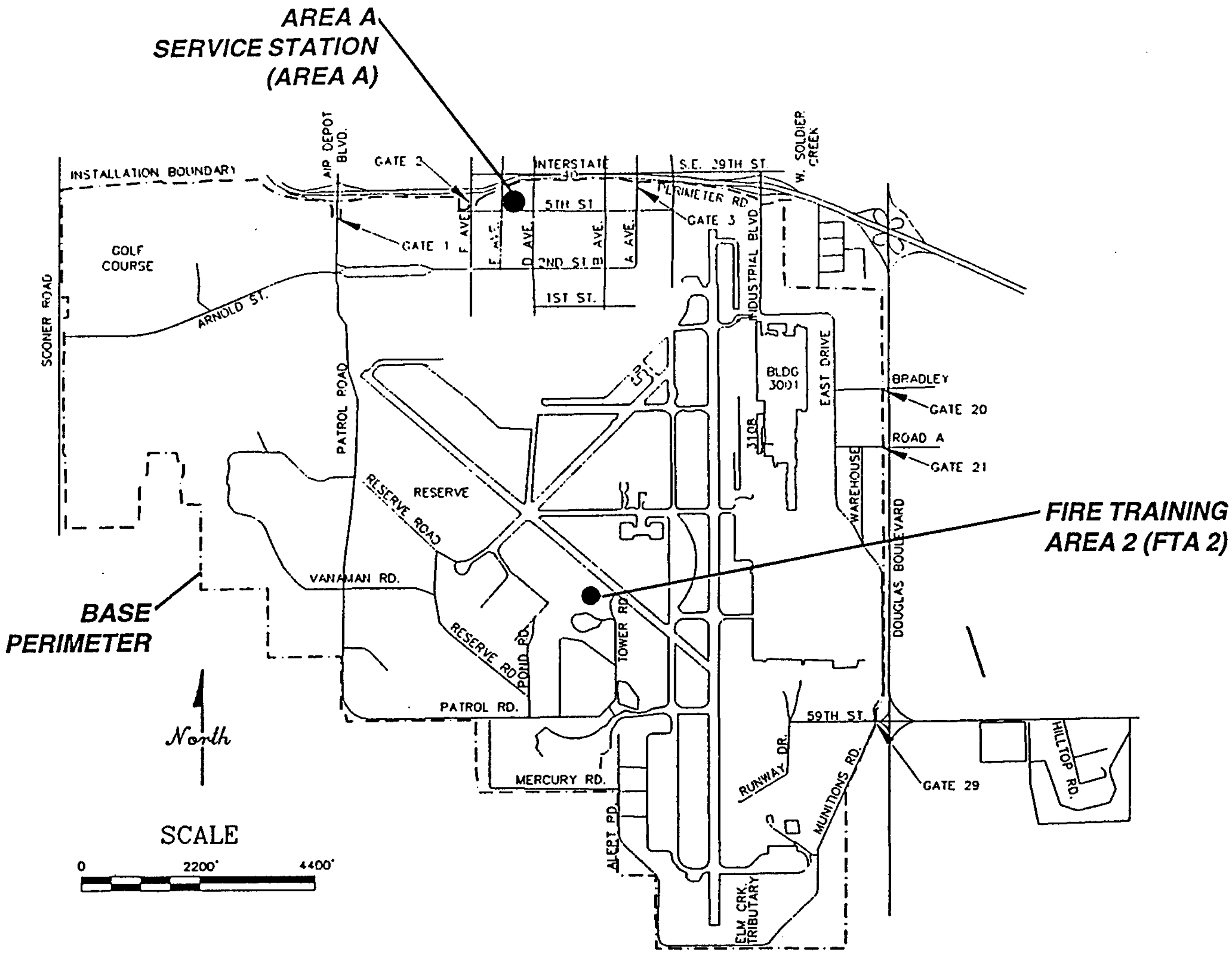
(SWMUs) and Areas of Concern (AOCs), including FTA 2 and Area A, and to perform corrective action at those identified as posing a threat to human health or the environment. Because the Base is a Department of Defense (DOD) facility, site investigation and remediation have progressed through the stages outlined under the Installation Restoration Program (IRP). In addition, soil and groundwater investigations at Area A are mandated under Oklahoma Administrative Code (OAC) 165:25-3-76.

1.2.1 FTA 2 Background

Site FTA 2 is located in the south-central portion of the Base, west of Tower Road and south of the main northwest to southeast Runway (Figure 1.2). FTA 2 was established as a temporary, unlined pit and was used infrequently for fire training exercises between 1962 and 1966. Standard operating procedures reportedly included adding water to the pit to saturate the soil to reduce infiltration. Fuel was then brought in by tank truck, placed on top of the water, ignited, and extinguished using water and foam. Any residues were left in the pit to evaporate and infiltrate until the next fire training exercise. Available air photographs indicate that the site is currently a gently sloping, open grassy area with no visible evidence of former training practices. Records for facility operation do not exist. Therefore, data on composition, frequency, and quantity of fuel or extinguishing agents used are not available.

In 1981, a Phase I study similar to a preliminary assessment/site inspection (PA/SI) was conducted by Engineering Science, Inc. (ES, 1982) as part of the Air Force IRP. The study identified 14 potentially contaminated sites, including Site FTA 2. Based on the findings of this study, the following have been completed:

- An IRP Response Action was performed by the USACE in 1987 (USACE, 1988). Soil samples from seven boreholes, drilled to a maximum depth of 7 feet



Source: Tetra Tech. Inc., 1996.

FIGURE 1.2

LOCATION OF SITES FTA 2 AND AREA A

Sites FTA 2 and Area A
RNA TS
Tinker AFB, Oklahoma

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below ground surface (bgs), were analyzed for volatile organic compounds (VOCs), semi-volatile organic compounds (SVOCs), and total metals.

- IT Corporation (IT) conducted a Phase I RCRA Facility Investigation (RFI) from October through December 1993, including soil sampling and the installation of four monitoring well pairs (IT, 1994). Soil and groundwater samples were analyzed for VOCs, SVOCs, and metals.

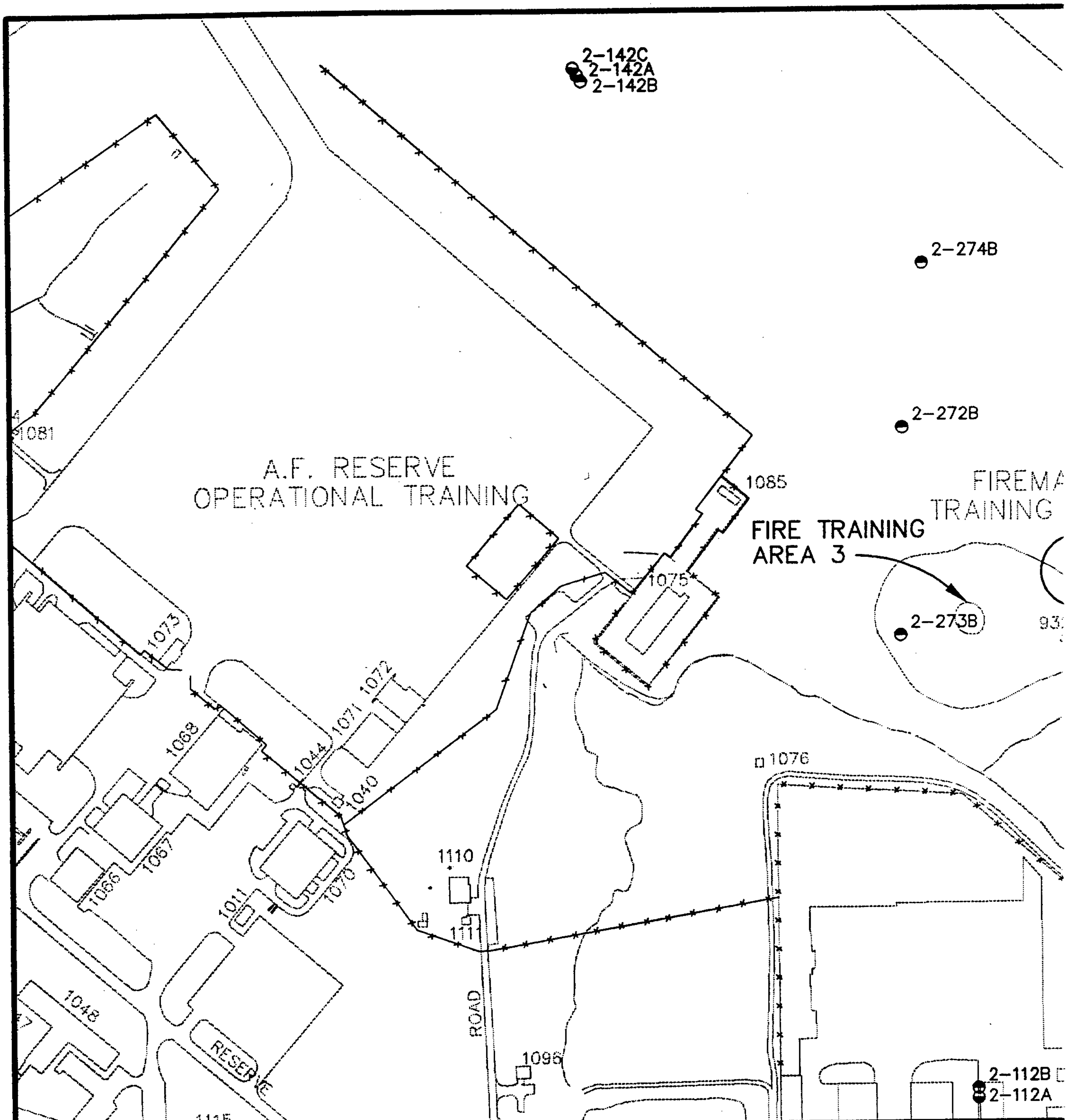
- A Phase II RFI was performed by Tetra Tech, Inc. (TT), in 1995 (TT Draft Report, 1996). Soil samples were collected from 5 soil boreholes and 2 additional boreholes constructed for monitoring wells. Soil analytical results were included in the Draft Report. The monitoring wells were subsequently completed and sampled by Tinker AFB.

- Since 1995, four additional monitoring wells have been installed and sampled for groundwater quality by Tinker AFB.

There are currently 14 groundwater monitoring wells (2-62A, 2-62B, 2-63A, 2-63B, 2-64A, 2-64B, 2-65A, 2-65B, 2-167B, 2-168B, 2-271B, 2-272B, 2-273B, and 2-274B) associated with FTA 2 (Figure 1.3). Additional upgradient and cross-gradient monitoring wells associated with other sites are also available for evaluating the extent of groundwater contamination in the general area.

1.2.2 Area A Background

Area A is located at the corner of "E" Avenue and Fifth Street in the north central portion of the Base (Figure 1.2). The site was the location of the Base service station facility for military vehicles from 1942 to 1992. Two 12,000-gallon underground storage tanks (USTs), Tanks 438 and 439, were installed in 1942 to store leaded gasoline, and were later used to store unleaded fuel. Two additional USTs were installed in 1975. Tank 411 with a 10,000-gallon capacity, was used to store unleaded



LEGEND

2-142B UPPER SATURATED ZONE MONITORING WELL LOCATION AND ID NUMBER

2-142A LOWER SATURATED ZONE MONITORING WELL LOCATION AND ID NUMBER

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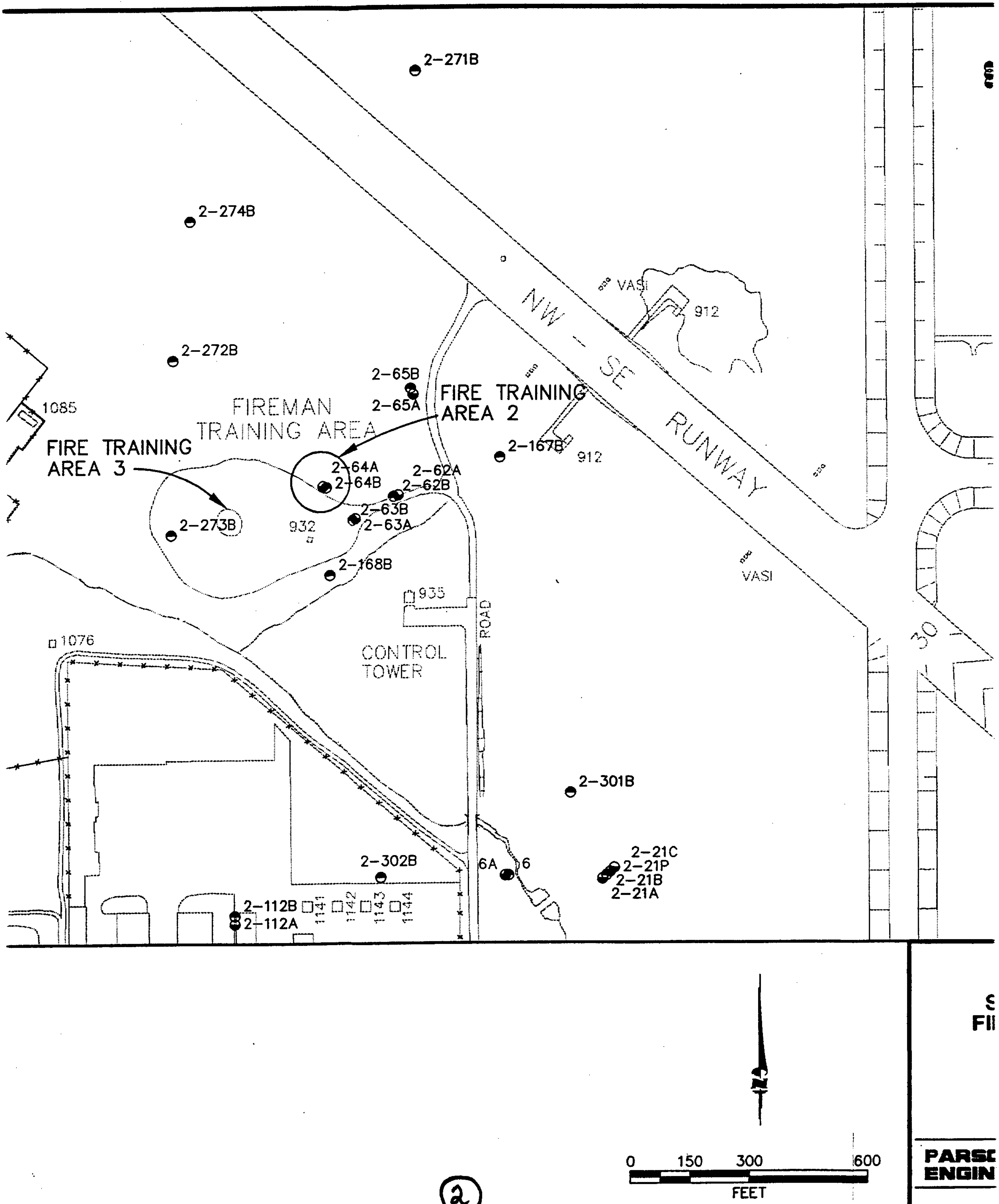
2-271B
2-274B
2-272B
2-65B
2-65A
1085
FIREMAN
TRAINING AREA
FIRE TRAINING
AREA 2
FIRE TRAINING
AREA 3
2-64A
2-64B
2-62A
2-62B
2-63B
2-63A
2-273B
932
2-167B
912
2-168B
935
VASI
912
NW - SE RUNWAY
VASI
30
ROAD
1076
CONTROL
TOWER
2-301B
2-21C
2-21P
2-21B
2-21A
6A
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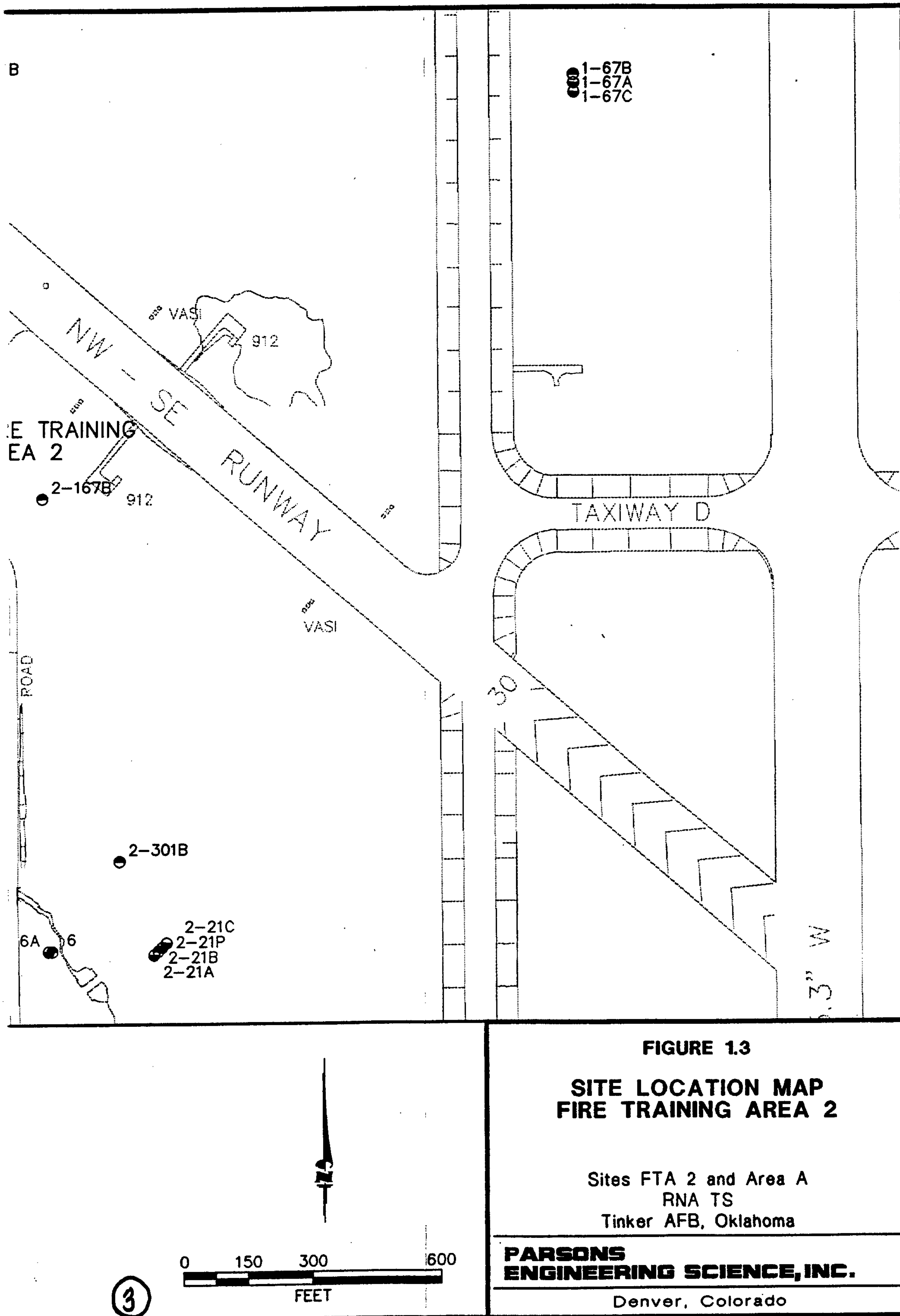

FIGURE 1.3

SITE LOCATION MAP
FIRE TRAINING AREA 2

Sites FTA 2 and Area A
RNA TS
Tinker AFB, Oklahoma

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3

gasoline, and Tank 402, of unknown size, was used to store diesel fuel. In 1978, USTs 438 and 439 were suspected of leaking and were consequently taken out of service on May 5, 1978. In 1982, Tank 411 developed a leak and was replaced with a tank of the same size and in the same location. USTs 411 and 402 were taken out of service in October 1990. The service station was officially closed in April 1991. All four USTs (Tanks 402, 411, 438, and 439) and associated piping were removed from the site in January 1996.

Site investigations and remedial measures were instituted in response to the leaking fuel tanks at the Area A Service Station. The following studies and remedial activities have been completed:

- An initial site investigation was performed by Environmental Recovery, Inc. (ERI) in July 1990. The investigation included five soil boreholes near Tanks 438 and 439. Soil and soil vapor samples were analyzed for BTEX, total petroleum hydrocarbons (TPH), and total lead (ERI, 1990).

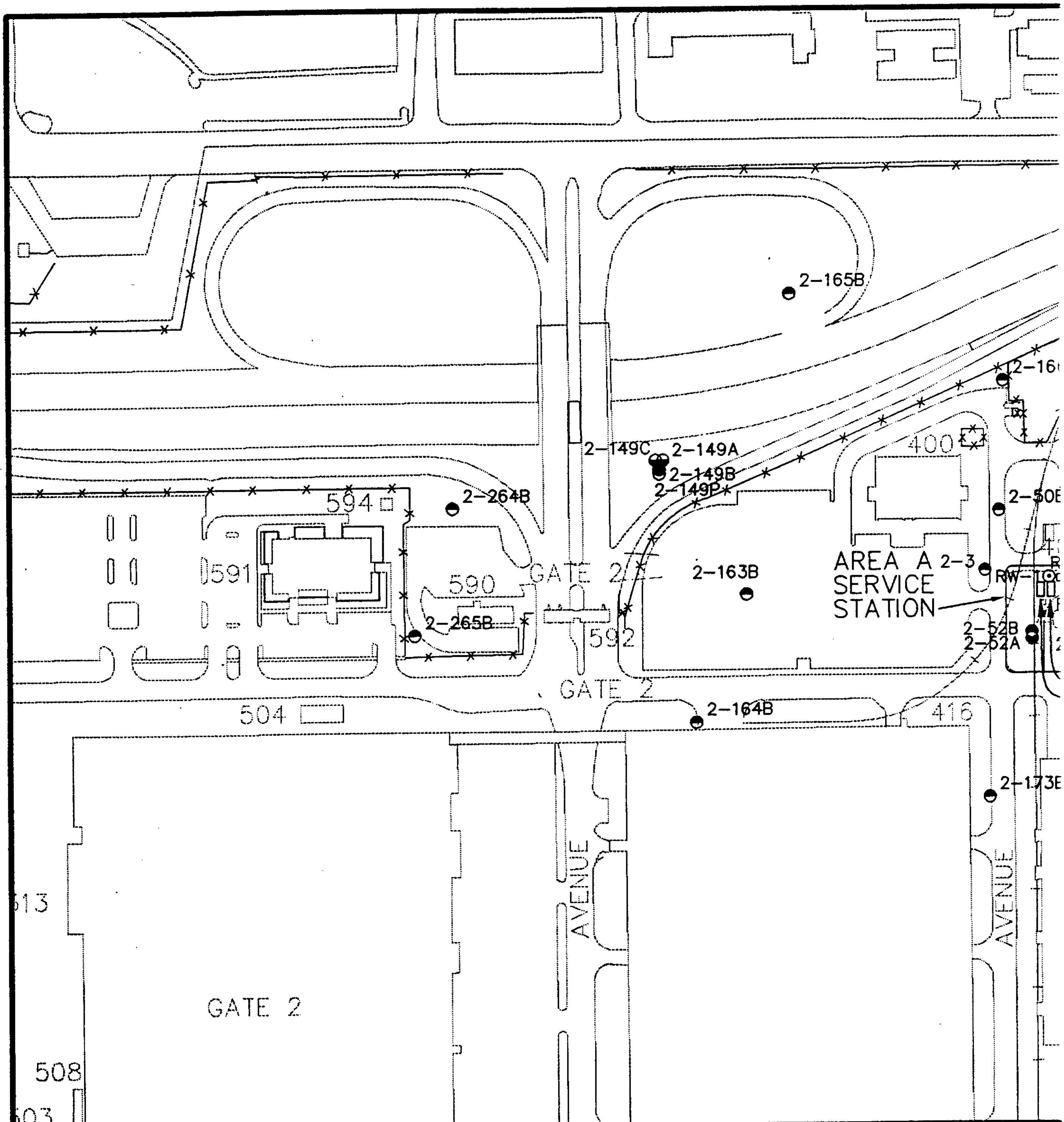
- A second site investigation was performed by Water and Soil Consultants, Inc. (WSCI) in 1991 and 1992 (WSCI, 1992). The investigation included a soil vapor survey in February 1991. On the basis of on the vapor survey, eight soil boreholes were drilled and soil samples analyzed for BTEX, TPH, and total lead. Three of the soil boreholes were completed as monitoring wells. A free product recovery system was also installed by WSCI in July 1992, consisting of three product recovery wells (WSCI, 1992).

- IT conducted a soil and groundwater investigation from October 1993 to March 1994 (IT, 1995a and 1993). Three soil boreholes were drilled and soil samples collected for analysis of VOCs, SVOCs, TPH, metals, and geotechnical parameters. Three monitoring wells were installed and groundwater samples were analyzed for VOCs, SVOCs, TPH, metals, and total organic carbon (TOC).

An additional four monitoring wells were installed in November and December 1993 as deeper well pairs.

- In January 1994, existing site monitoring wells were sampled and analyzed for VOCs, SVOCs, and metals (IT, 1996).
- In January 1995, existing site monitoring wells were sampled and analyzed for VOCs, SVOCs, and metals (IT, 1996).
- A temporary groundwater probe investigation was conducted by IT from April to May 1995 (IT, 1995c). Twenty temporary groundwater points were sampled and analyzed for VOCs.
- Ten additional monitoring wells were installed in June 1995 by IT (IT, 1995b). In October 1995 existing site monitoring wells were sampled and analyzed for VOCs, SVOCs, and metals.
- Two additional monitoring wells were installed by Tinker AFB in June 1996. In August 1996 existing site monitoring wells were sampled and analyzed for VOCs, SVOCs, and metals (Tinker AFB, 1996).

There are currently 17 groundwater monitoring wells (2-2, 2-2A, 2-3, 2-4, 2-4A, 2-50B, 2-51A, 2-51B, 2-52A, 2-52B, 2-163B, 2-164B, 2-165B, 2-166B, 2-173B, 2-264B, and 2-265B) associated with Area A (Figure 1.4). Additional upgradient and cross-gradient monitoring wells associated with other sites are also available for evaluating the extent of groundwater contamination in the general area.



LEGEND

2-165B	UPPER SATURATED ZONE MONITORING WELL LOCATION AND ID NUMBER
2-2A	LOWER SATURATED ZONE MONITORING WELL LOCATION AND ID NUMBER
RW-1	PRODUCT RECOVERY WELL
WS-32	WATER SUPPLY WELL

NOTE:

TANK NOS. 402, 411, 438 AND 439 HAVE BEEN REMOVED.

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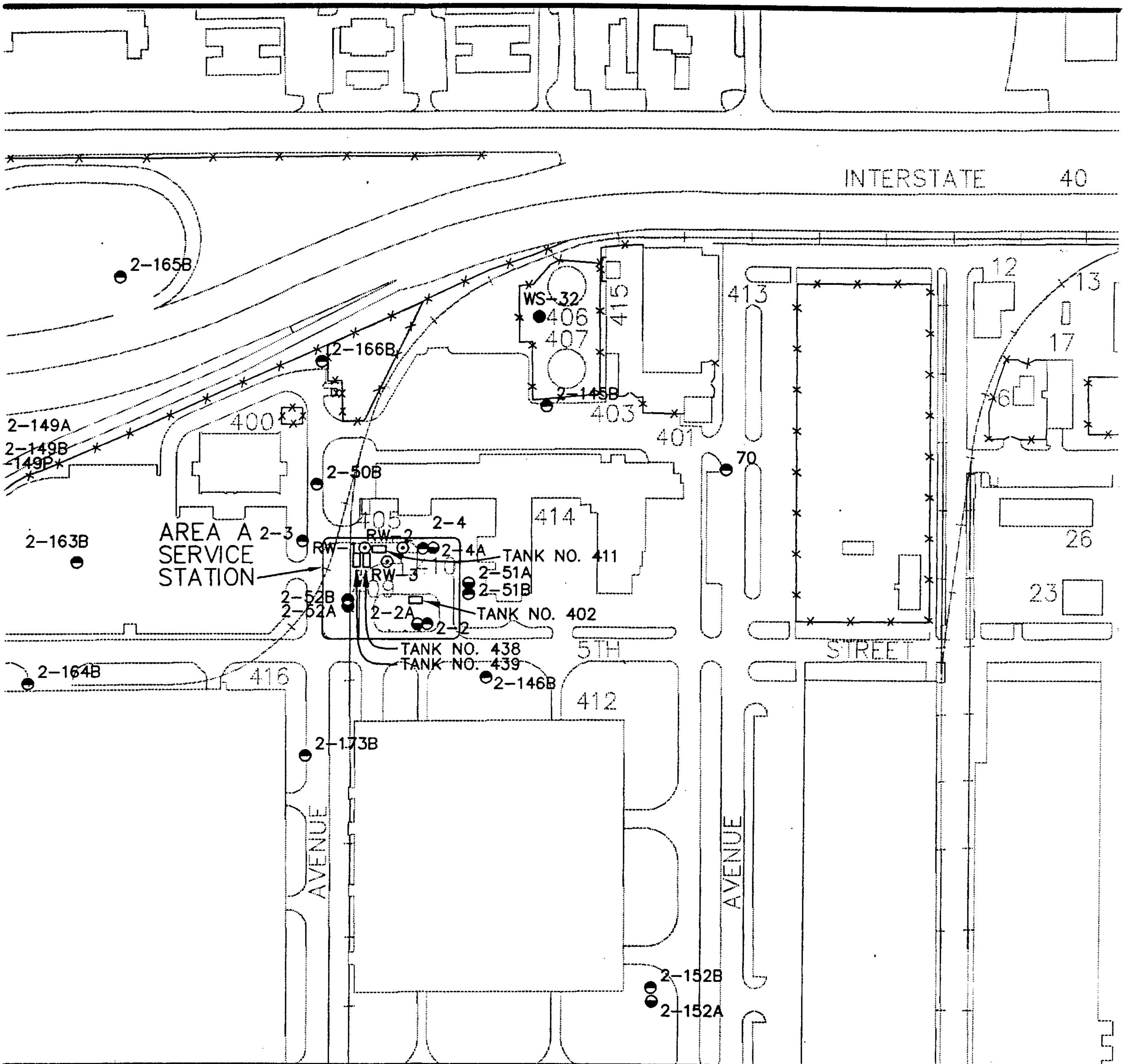

NOTE:

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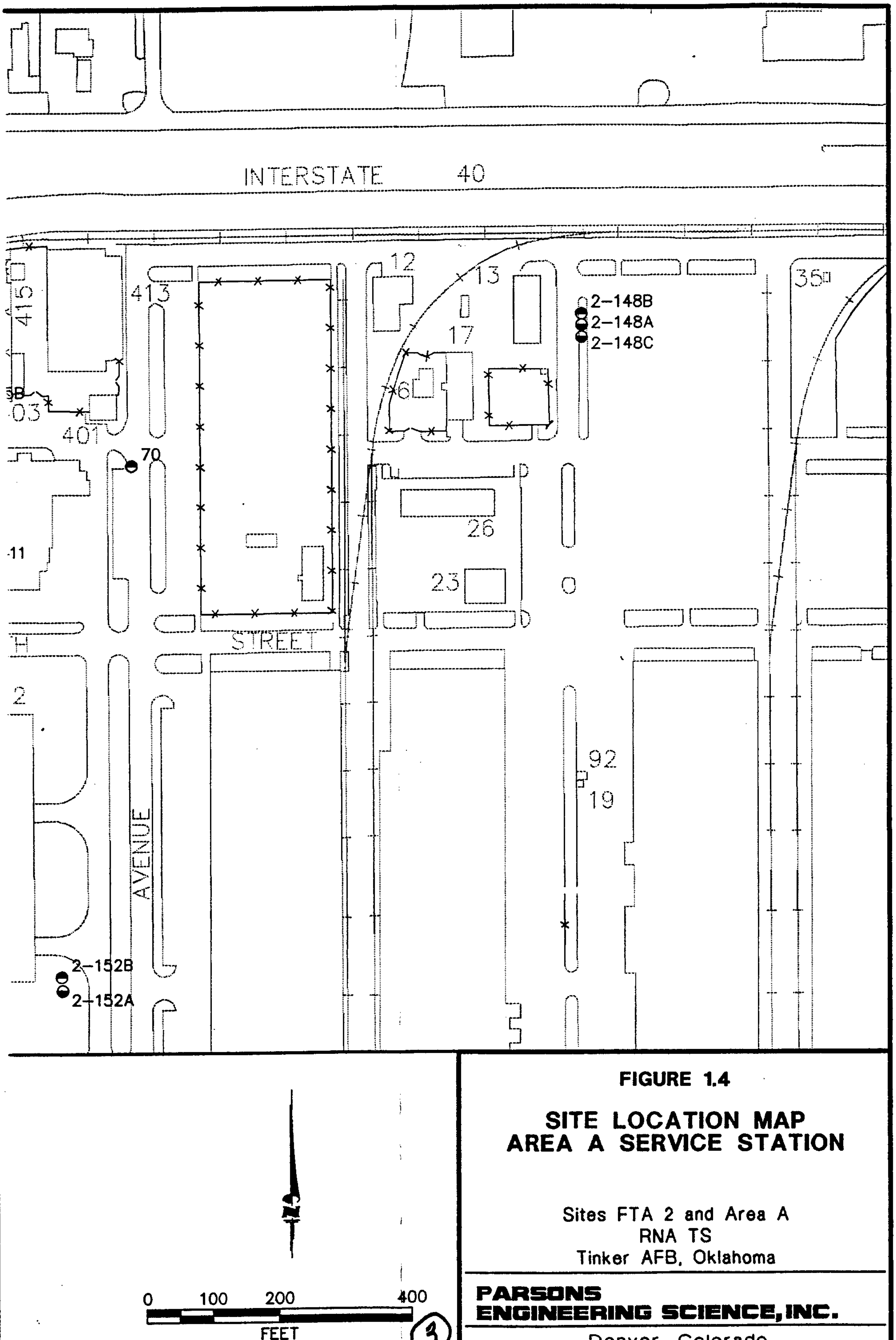

FIGURE 1.4

SITE LOCATION MAP
AREA A SERVICE STATION

Sites FTA 2 and Area A
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SECTION 2

DATA REVIEW AND CONCEPTUAL MODEL DEVELOPMENT

Site-specific data were reviewed and used to develop conceptual models for groundwater flow and contaminant transport regimes at Sites FTA 2 and Area A. The conceptual models guided the selection of sampling locations and the analytical data requirements needed to support the modeling efforts and to evaluate potential remediation technologies, including natural attenuation. Section 2.1 presents a synopsis of available site characterization data. Section 2.2 presents the preliminary conceptual groundwater flow and solute transport models that were developed on the basis of these data.

2.1 DATA REVIEW

The following sections are based upon review of data from the following sources:

- Draft Report, RCRA Facility Investigation Report for Selected Appendix I Sites at Tinker Air Force Base, OK (TT, 1996);

- Final Report, Investigation for Soil and Groundwater Cleanup Report, Area A Service Station, Tinker Air Force Base, Oklahoma (IT, 1996);

- Temporary Groundwater Probe Investigation Report, Area A Service Station, Tinker Air Force Base, Oklahoma (IT, 1995c); and

- Final Report, Phase I RCRA Facility Investigation for Appendix I Sites, Volume I, SWMU-8, Fire Training Area 2 (IT, 1994).

2.1.1 Topography, Surface Hydrology, and Climate

Tinker AFB is located in central Oklahoma and topography varies from almost level to gently rolling. The local relief is a result of dissection by erosional activity and stream channel development. Ground surface elevations at Tinker AFB range from 1,190 feet above the National Geodetic Vertical Datum (NGVD) near the northwest corner where Crutcho Creek intersects the Base boundary, to 1,320 feet NGVD at Area D, located east of the main installation. Topographic maps of Sites FTA 2 and Area A at Tinker AFB are presented as Figures 2.1 and 2.2, respectively.

Surface water runoff from the Base primarily drains to diversion structures and then to intermittently flowing surface streams. The north and west portions of the Base drain to Crutcho Creek, a tributary of the North Canadian River. Kuhlman Creek also collects drainage from the northwest portion of the Base and discharges into Crutcho Creek north of the Base. The northeast portion of the Base is drained primarily by tributaries of Soldier Creek, which is also a tributary of Crutcho Creek. Two small unnamed intermittent tributaries of Elm Creek cross installation boundaries south of the main runway, and generally do not receive significant quantities of Base runoff due to site grading designed to preclude such drainage. These streams, when flowing, extend to Stanley Draper Lake, approximately one-half mile south of the Base.

In the area of FTA 2, topography slopes gently to the southwest, towards Crutcho Creek, with elevations ranging from 1240 to 1250 feet NGVD. The sloping topography is modified by an incised channel of a southwest-flowing tributary to Crutcho Creek. The channel of this tributary is approximately 5 to 10 feet below the grade of the surrounding terrain. Surface water run-off at FTA 2 travels southeast to this southwest-draining tributary. The tributary emerges from a culvert located approximately 200 feet east of FTA 2, after draining an area occupied by industrial facilities on the east side of the airfield.

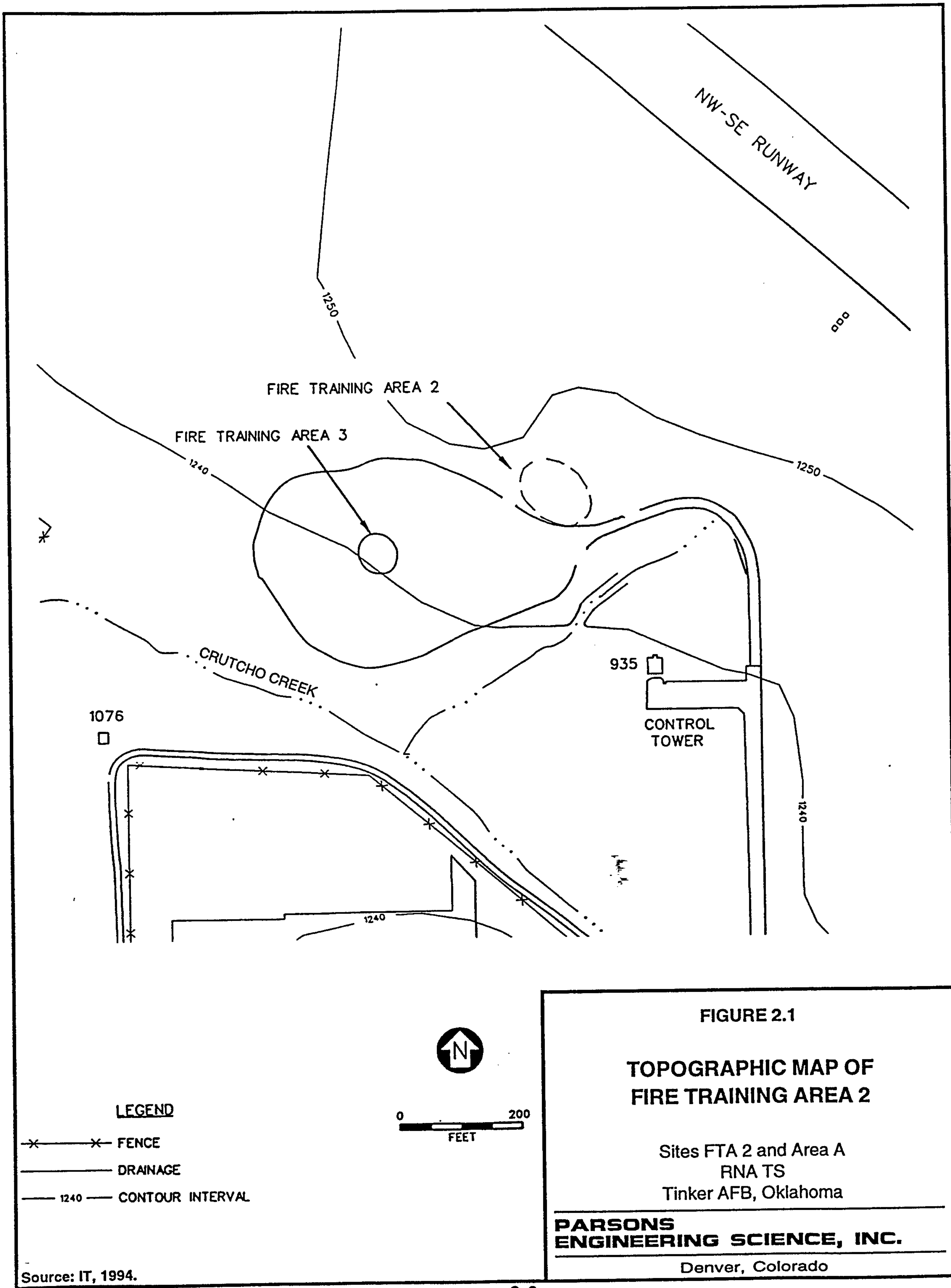


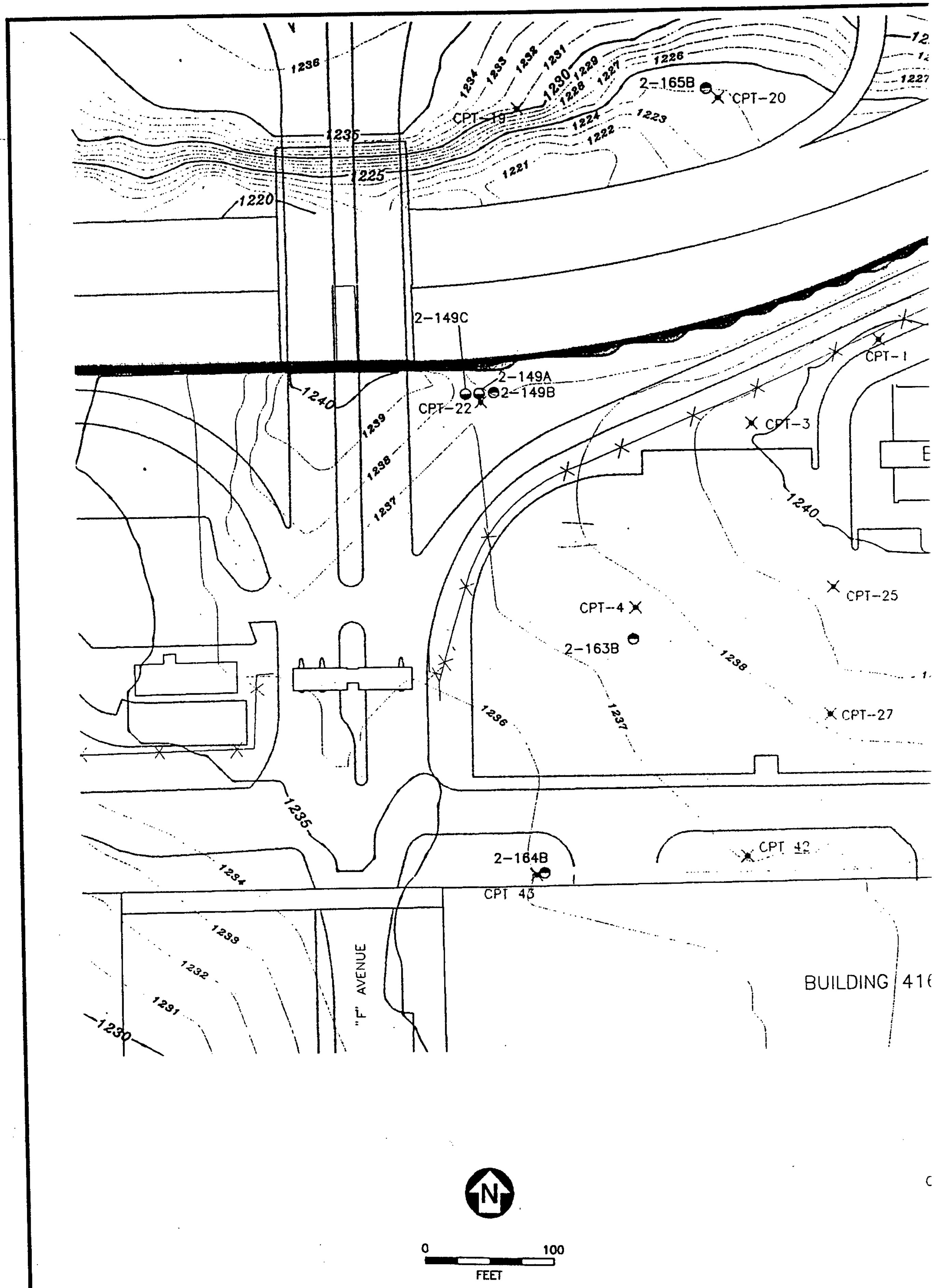
FIGURE 2.1

TOPOGRAPHIC MAP OF FIRE TRAINING AREA 2

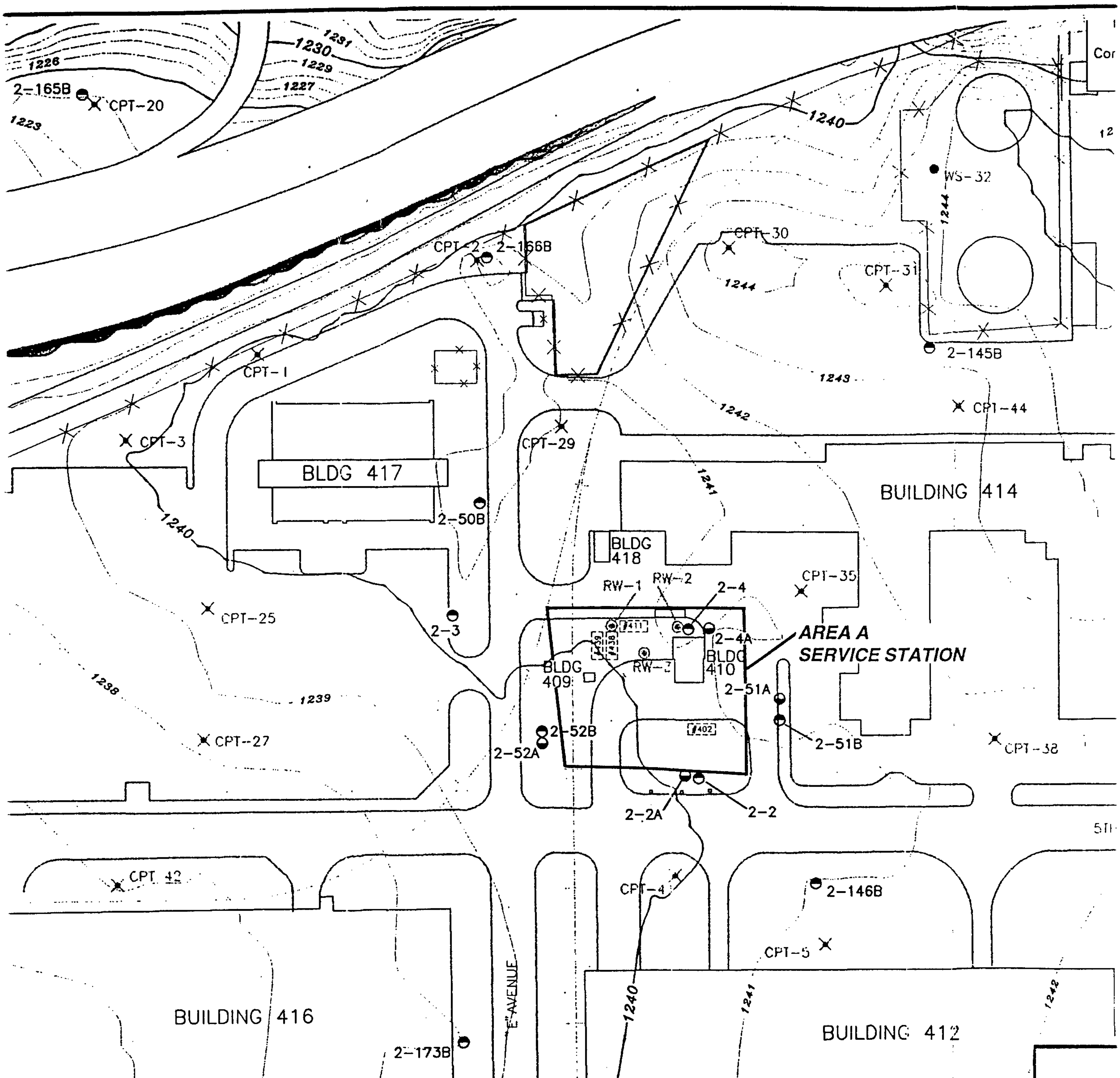
Sites FTA 2 and Area A
RNA TS
Tinker AFB, Oklahoma

PARSONS ENGINEERING SCIENCE, INC.

Denver, Colorado

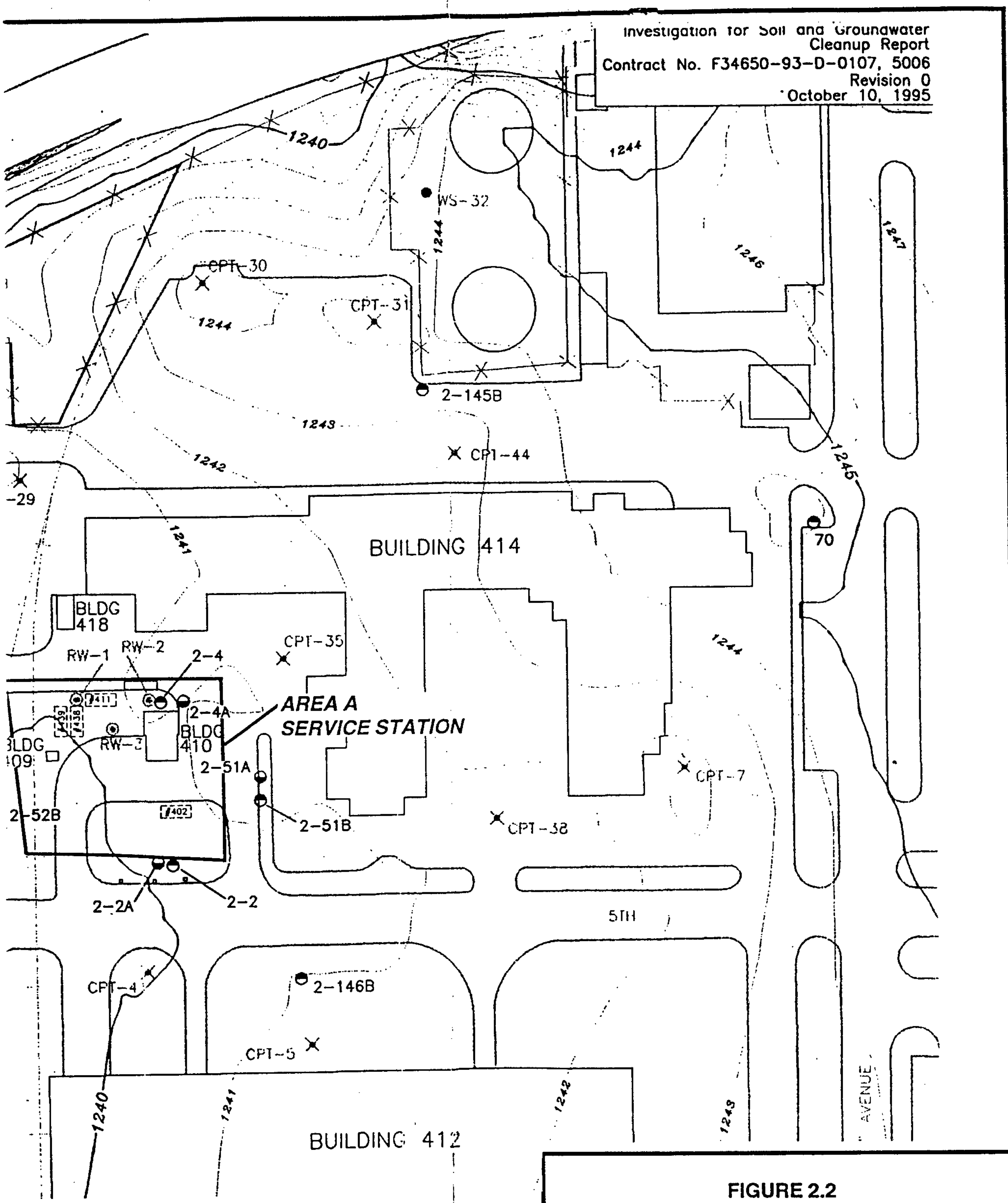


Sources: Tinker AFB, 1997; and IT, 1996.



LEGEND

RW-2	RECOVERY WELL LOCATION AND ID NUMBER (WSCI, 1992)
CPT-44	TEMPORARY GROUNDWATER PROBE SAMPLE LOCATION AND ID NUMBER
2-51B	UPPER SATURATED ZONE MONITORING WELL LOCATION AND ID NUMBER
2-51A	LOWER SATURATED ZONE MONITORING WELL LOCATION AND ID NUMBER
WS-32	WATER SUPPLY WELL
402	LOCATION OF INACTIVE/CLOSED UNDERGROUND STORAGE TANK
	FENCE
1240	5 FOOT CONTOUR INTERVAL (FEET – DATUM: NGVD)
1239	1 FOOT CONTOUR INTERVAL (FEET – DATUM: NGVD)



AND

PROBE
NUMBER

MONITORING WELL

MONITORING WELL

LOCATION OF INACTIVE/CLOSED UNDERGROUND STORAGE TANK

FENCE

1240 5 FOOT CONTOUR INTERVAL (FEET - DATUM: NGVD)

1239 1 FOOT CONTOUR INTERVAL (FEET - DATUM: NGVD)

FIGURE 2.2

TOPOGRAPHIC MAP OF AREA A SERVICE STATION

Sites FTA 2 and Area A
RNA TS
Tinker AFB, Oklahoma

PARSONS ENGINEERING SCIENCE, INC.
Denver, Colorado

In Area A the ground surface slopes to the west and elevations range from 1230 to 1247 feet NGVD. Surface drainage from the site is directed into Kuhlman Creek to the west of the site. Kuhlman Creek discharges into Crutcho Creek north of the Base.

The climate in central Oklahoma is continental, and is characterized by cold winters, hot summers, and moderate rainfall. Precipitation averages 33 inches per year. Annually, potential evaporation usually exceeds precipitation. Maximum evaporation occurs during June, July, and August.

2.1.2 Overview of Geology and Hydrogeology

The following sections provide an overview of regional and site geology and hydrogeology.

2.1.2.1 Regional Geology

Tinker AFB is located within the Central Redbed Plain Section of the Central Lowland Physiographic Province, which is tectonically stable. No major faults or fracture zones have been mapped near Tinker AFB. Tinker AFB is underlain by several thousand feet of sedimentary strata that range in age from Cambrian to Permian and overlie a Precambrian igneous basement. The major lithologic units in the area of Tinker AFB are relatively flat-lying and have a regional westward dip of approximately 40 feet per mile (ft/mile) (Bingham and Moore, 1975).

Geologic units that outcrop at Tinker AFB consist of, in descending order, Quaternary Alluvium, the Hennessey Group, and the Garber Sandstone (Table 2.1, Figure 2.3). The Wellington Formation crops out to the east of Tinker AFB. Quaternary alluvium and terrace deposits overlie bedrock in and near present-day stream valleys. Quaternary deposits consist of unconsolidated soils from weathered bedrock, eolian sands, and interfingering lenses of fluvial sands, silts, clays and gravels. Terrace deposits are exposed where stream valleys downcut through older

TABLE 2.1
MAJOR GEOLOGIC UNITS IN THE VICINITY OF TINKER AFB
SITES FTA2 AND AREA A RNA TS
TINKER AFB, OKLAHOMA

System	Series	Stratigraphic unit	Thickness (feet)	Description and Distribution	Water-Bearing Properties
QUATERNARY	PLEISTOCENE AND RECENT	Alluvium	0-70	Unconsolidated, with interfingering lenses of sand, silt, clay, and gravel in flood plains and stream channels.	Moderately permeable. Yields small to moderate quantities of water in valleys of larger streams. Water is very hard, but suitable for most uses, unless contaminated by industrial wastes or oil field brines
		Terrace deposits	0-100	Unconsolidated, with interfingering lenses of sand, silt, gravel, and clay that occur at one or more levels above flood plains and principal streams.	Moderately permeable. Where deposits have sufficient saturated thickness, they are capable of yielding moderate quantities of water to wells. Water is moderately hard to very hard, but less mineralized than water in other aquifers. Suitable for most uses unless contaminated by oil field brines.

TABLE 2.1 (Continued)
MAJOR GEOLOGIC UNITS IN THE VICINITY OF TINKER AFB
SITES FTA2 AND AREA A RNA TS
TINKER AFB, OKLAHOMA

System	Series	Stratigraphic unit	Thickness (feet)	Description and Distribution	Water-Bearing Properties
PERMIAN	LOWER PERMIAN	Hennessey Group (includes Kingmen Siltstone and Fairmont Shale)	700	Deep-red clay shale containing thin beds of red sandstone and white or greenish bands of sandy or limey shale. Forms relatively flat to gently rolling grass-covered prairie.	Poorly permeable. Yields meager quantities or very hard, moderately to highly mineralized water to shallow domestic and stock wells. In places, water contains elevated levels of sulfate.
		Garber Sandstone	500±	Deep-red to reddish-orange sandstone, massive and cross-bedded and interfingered with red shale and siltstone.	Poorly to moderately permeable. Important source of groundwater in Cleveland and Oklahoma counties. Yields small to moderate quantities of water to deep wells; heavily pumped for industrial and municipal uses in the Norman and Midwest City areas. Water from shallow wells hard to very hard; water from deep wells moderately hard to soft. Lower part contains water too salty for domestic and most industrial uses.
		Wellington Formation	500±	Deep-red to reddish-orange massive and cross-bedded fine-grained sandstone interbedded with red, purple, maroon, and gray shale. Base of information not exposed in the area.	

Source: Modified from Wood and Burton, 1968.

022/729691/21.DOC

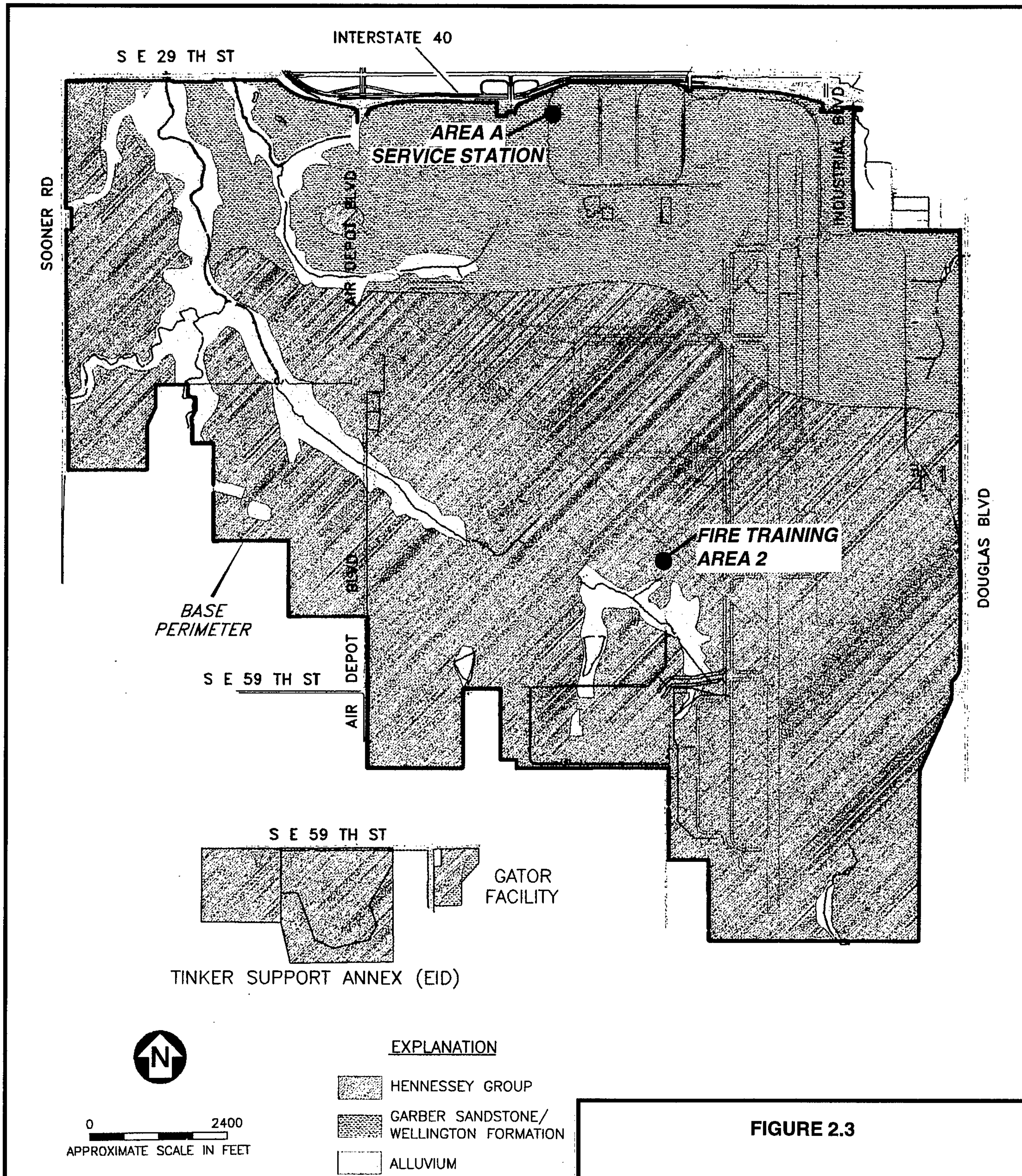


FIGURE 2.3

SURFACE GEOLOGIC MAP
TINKER AIR FORCE BASE

Sites FTA 2 and Area A
RNA TS
Tinker AFB, Oklahoma

PARSONS
ENGINEERING SCIENCE, INC.

Denver, Colorado

Source: Tinker AFB, 1991; IT, 1996.

strata, leaving them topographically higher than present day valley floors. Alluvial sediments range in thickness from less than a foot to nearly 20 feet.

The Hennessey Group, Garber Sandstone, and Wellington Formation are Permian in age (230 to 280 million years ago), and consist of a conformable sequence of sands, silts, and clays with lenticular beds that vary in thickness over short horizontal distances. Because of similar lithologies and lack of fossils or key beds, the Garber Sandstone and the Wellington Formation are difficult to distinguish and are informally grouped as the Garber-Wellington Formation. Together these units are approximately 900 feet thick beneath Tinker AFB.

The Hennessey Group outcrops on the central, southern, and western portions of the Base, generally to the west and south of Crutcho Creek (Figure 2.3). The Hennessey Group is composed of the Kingman Siltstone and the Fairmont Shale (Miser *et al.*, 1954; Bingham and Moore, 1975). The Hennessey Group thins from approximately 70 feet in the southwest part of the Base towards its erosional edge across the northeastern part of the Base. The contact between the Hennessey group and the underlying Garber Sandstone is often difficult to distinguish. The unit is composed of red shale and thin beds of fine sandstone.

The Garber Sandstone outcrops across the northern, central, and eastern portions of the Base, and is generally covered by a thin veneer of soil or alluvium up to 20 feet thick (Figure 2.3). The Garber Sandstone conformably underlies the Hennessey Group and consists of dominantly fine sandstone, with lesser amounts of siltstone and shale. Outcrops north of the base are characterized by small to medium channels with cross-bedded sandstones featuring cut and fill structures. Geophysical and lithologic logs of soil boreholes drilled on Base indicate that 65 to 70 percent of the Garber Sandstone and Wellington Formation are composed of sandstone. The sandstones are typically fine to very fine grained, friable, and poorly cemented. However, the sandstone

intervals are locally cemented, typically at the base of sandstone lenses, by quartz, carbonate or iron-bearing minerals. These cemented intervals form horizons resistant to drilling. Shale intervals are generally discontinuous, and range in thickness from a few inches to 40 feet.

2.1.2.2 Regional Hydrogeology

Tinker AFB overlies a regional source of potable water, the Central Oklahoma aquifer system. The productive formations of the aquifer include the Permian redbeds, including parts of the Permian Garber Sandstone and Wellington Formation, and Quaternary alluvium and terrace deposits. The Central Oklahoma aquifer has been classified as a Class IA aquifer by the State of Oklahoma, signifying that it is an irreplaceable source of public water supply (State of Oklahoma Water Resources Board, 1994). Water from the Central Oklahoma aquifer is used for municipal, industrial, domestic and agricultural purposes. Tinker AFB presently derives most of its water from a system of 26 operable water wells constructed generally along the east and west margins of the base, and from the Oklahoma City Water Department. All Base wells are completed in the Garber-Wellington Formation at depths of 400 to 1,100 feet.

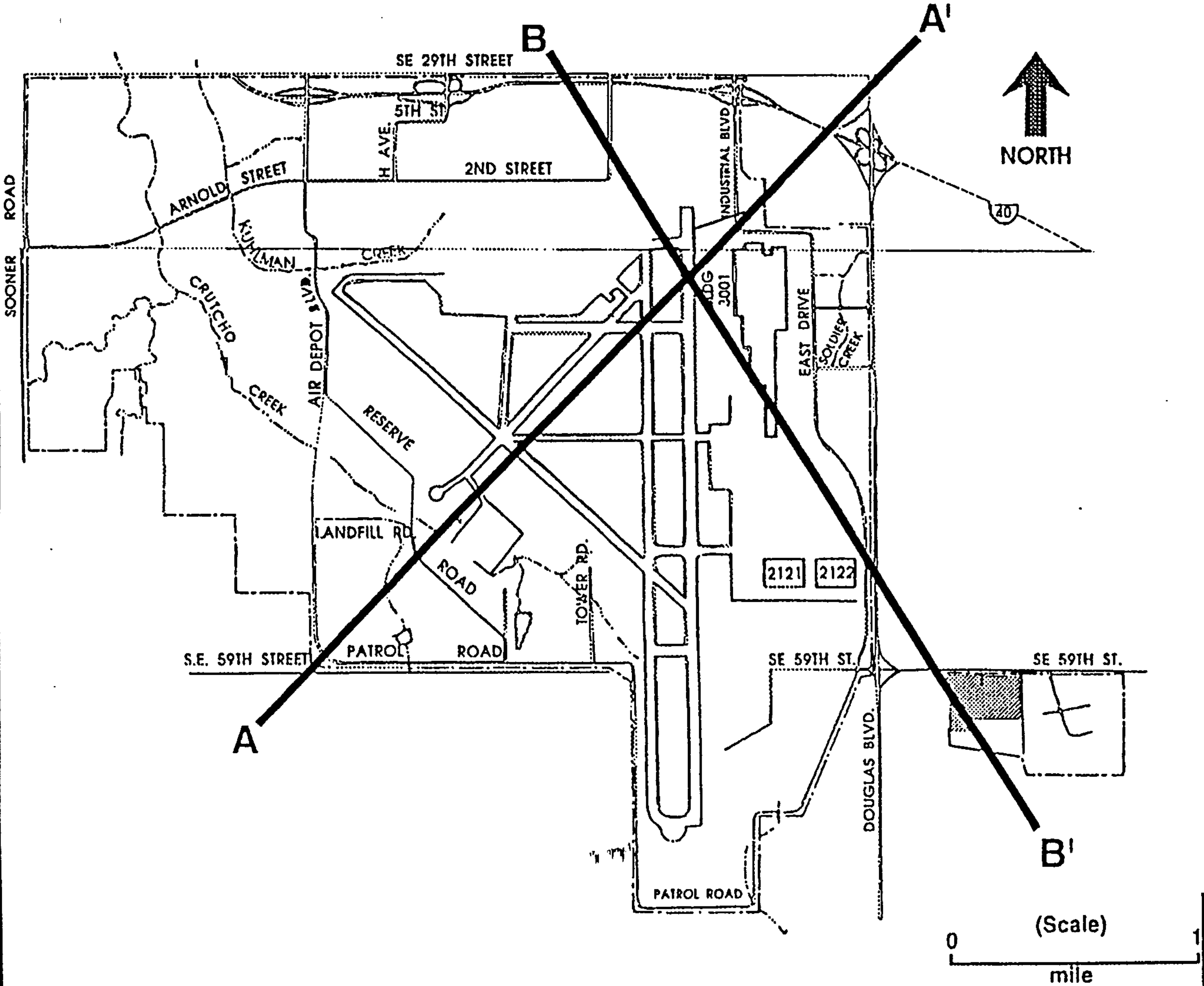
Groundwater in the Central Oklahoma aquifer is derived primarily from precipitation infiltrating outcrops of the geologic units. Infiltration of surface waters from streams crossing the outcrops is believed to be a minor source of recharge to the aquifer (Parkhurst *et al.*, 1993). Tinker AFB is located in the outcrop area of the Garber Sandstone and is therefore in the recharge zone of the aquifer.

The groundwater system at Tinker AFB has been divided into four hydrogeologic zones: the Hennessey Water-Bearing Zone (HWBZ), the Upper and Lower Saturated Zones (USZ and LSZ), and the Producing Zone of the regional Garber-Wellington aquifer. The HWBZ occurs within the Hennessey Group and is perched above the USZ over the southwest portion of the Base. The LSZ and USZ are regionally considered to

be in the upper third of the Garber-Wellington aquifer and generally are present at depths of less than 200 feet bgs. The Producing Zone generally is considered to be greater than 200 bgs, and is used for water supply at Tinker AFB.

Figure 2.4 shows the locations of regional hydrogeologic cross-sections A-A' (Figure 2.5) and B-B' (Figure 2.6). The HWBZ is perched within the Hennessey Group on the southwestern portion of the Base. The USZ generally behaves as a water table aquifer in the eastern part of the Base, but could be confined in localized portions of the Base where intra-USZ clay lenses intersect the USZ piezometric surface. The depth to the USZ water table ranges from zero feet bgs northeast and east of the Base to approximately 40 feet bgs in the southwest part of the Base. The regional stratigraphic dip of 0.0076 feet per foot (ft/ft) to the west-southwest produces a general westward groundwater flow pattern in the USZ. Hydraulic gradients in the USZ across Tinker AFB range from 0.0034 to 0.018 ft/ft and average 0.0076 ft/ft. A low-permeability zone, characterized by high clay content and well-cemented silts and sands in the USZ, acts as an aquitard between the USZ and the LSZ.

The LSZ is considered one hydraulic unit from the USZ/LSZ aquitard to an approximate depth of 200 feet bgs. Due to variations in topography, the top of the LSZ is found at depths of 10 to 100 feet bgs. The LSZ extends east of the Base beyond the limits of the USZ and is the shallowest groundwater zone screened in off-Base wells. Across the central portion of the Base, the vadose zone at the top of the LSZ disappears where the overlying clay layer dips below the surface of the LSZ. At some locations the LSZ may be confined by the overlying clay layer. A low-permeability zone at the base of the LSZ (characterized by high clay content) acts as an aquitard between the LSZ and the Producing Zone. The Producing zone extends from 200 to greater than 900 feet bgs and is under confined conditions.



Source: IT, 1994.

FIGURE 2.4

LOCATION OF HYDROGEOLOGIC CROSS-SECTIONS A-A' AND B-B'

Sites FTA 2 and Area A
RNA TS
Tinker AFB, Oklahoma

PARSONS ENGINEERING SCIENCE, INC.
Denver, Colorado

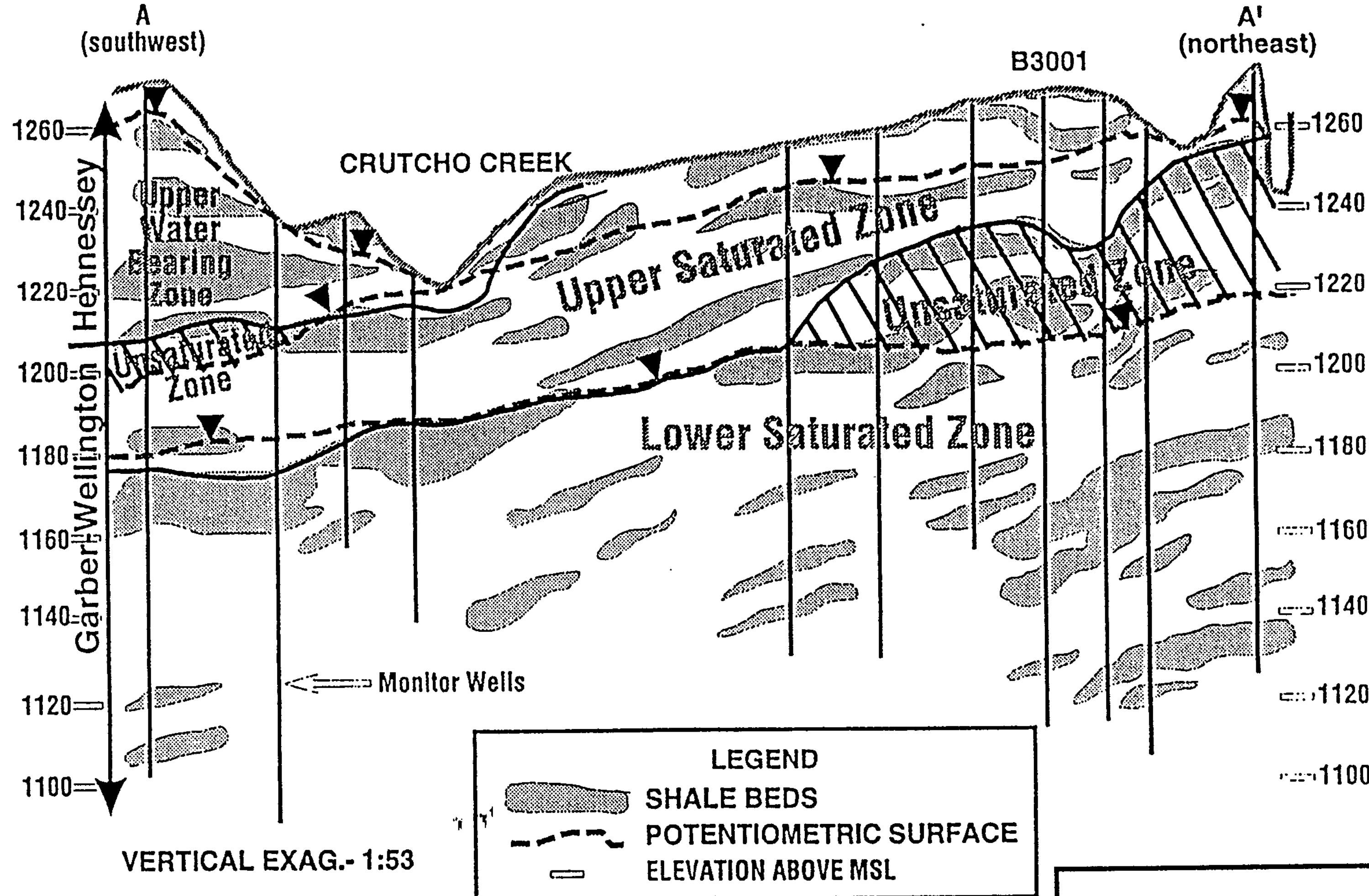


FIGURE 2.5

HYDROGEOLOGIC
CROSS-SECTION A-A'

Sites FTA 2 and Area A
RNA TS
Tinker AFB, Oklahoma

PARSONS
ENGINEERING SCIENCE, INC.
Denver, Colorado

Source: IT, 1994.

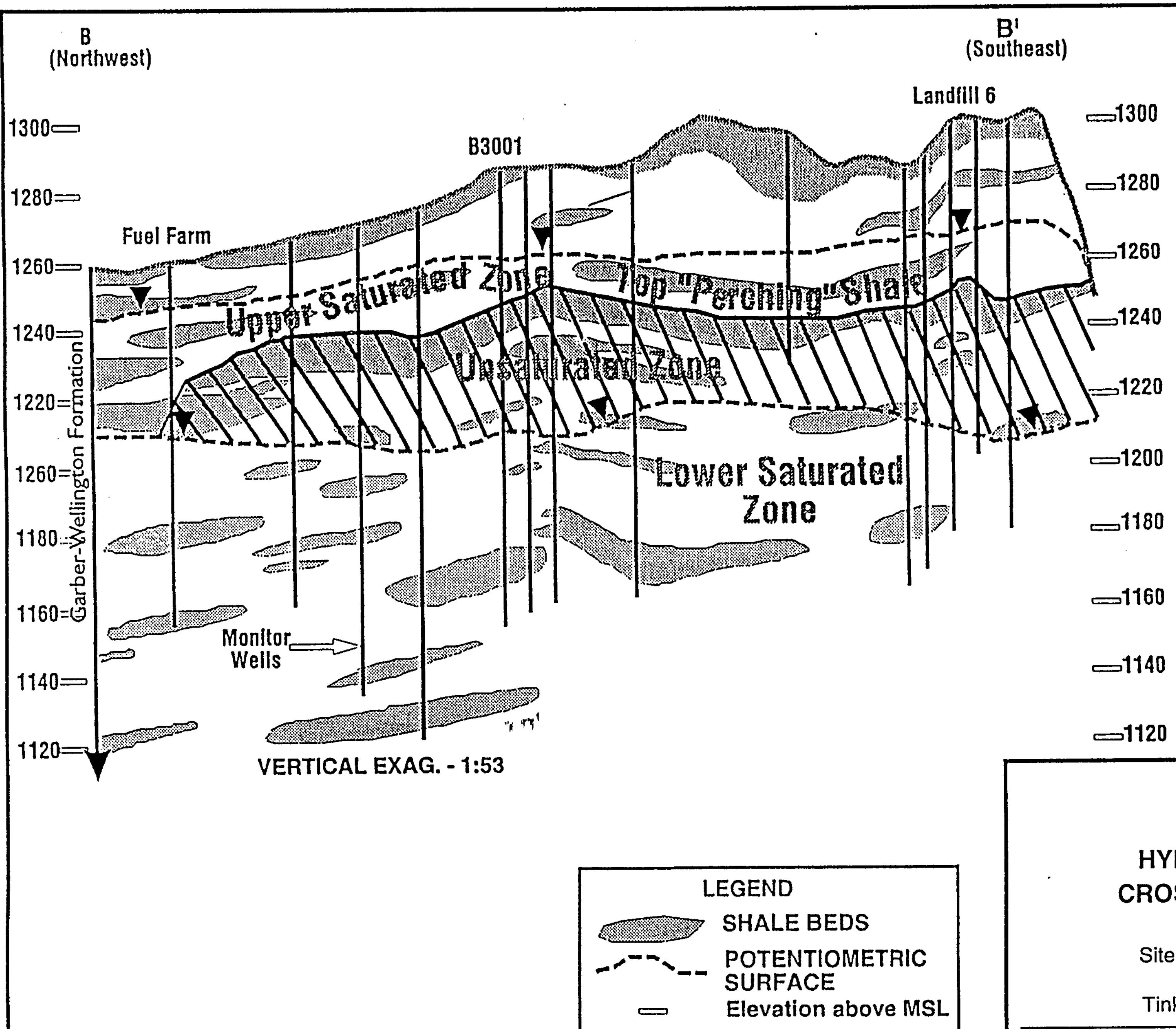


FIGURE 2.6

HYDROGEOLOGIC CROSS-SECTION B-B'

Sites FTA 2 and Area A
RNA TS
Tinker AFB, Oklahoma

PARSONS ENGINEERING SCIENCE, INC.
Denver, Colorado

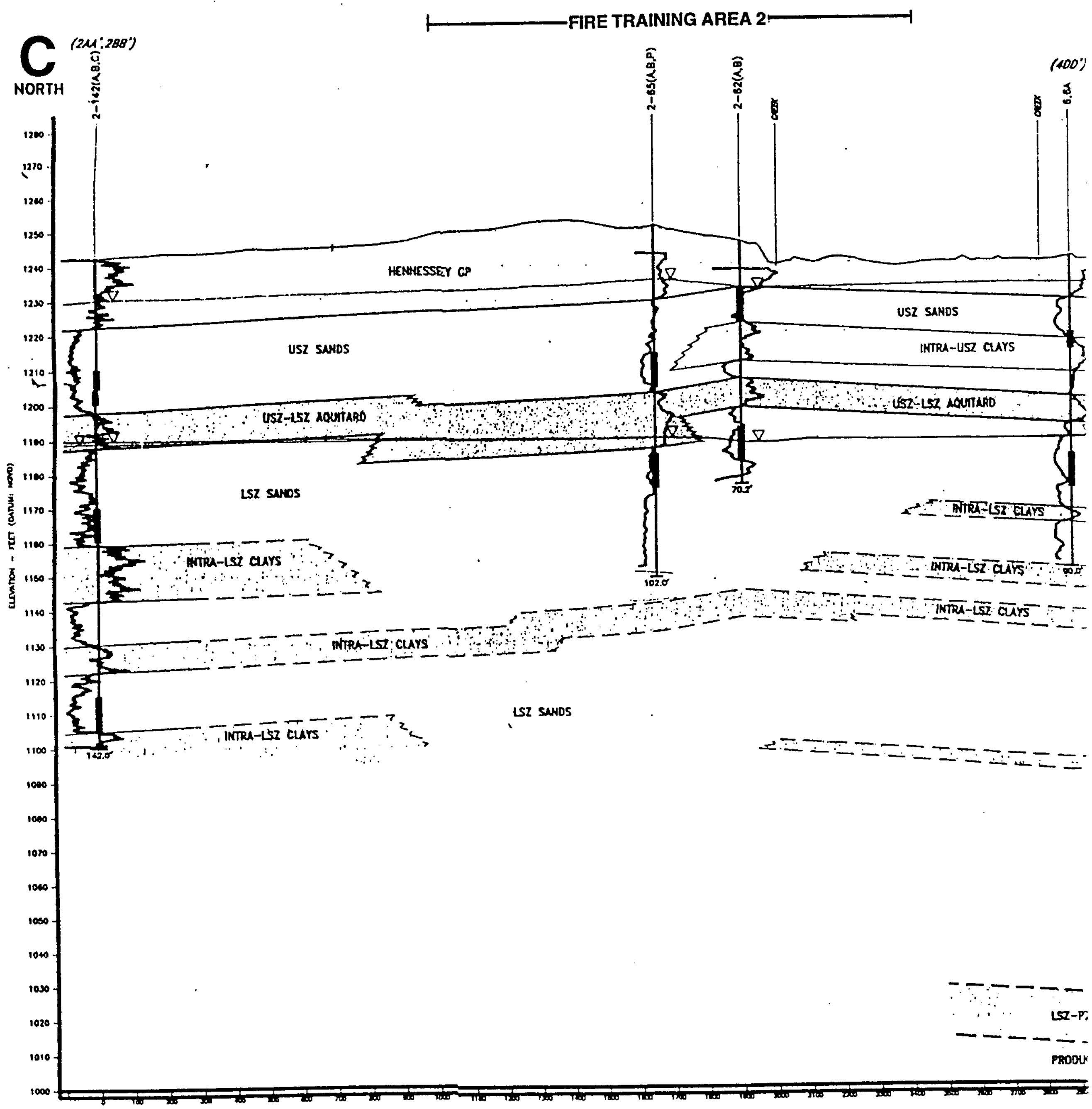
Source: IT, 1994.

2.1.2.3 FTA 2 Geology and Hydrogeology

The geology at FTA 2 closely matches the description of the regional geology. FTA 2 hydrogeologic cross-section C-C' (Figure 2.7) illustrates the stratigraphy through the center of the site perpendicular to the direction of groundwater flow. Approximately 8 to 15 feet of reddish silty clay or clayey silt of the Hennessey Group overlies sands of the Garber Sandstone. The Garber Sandstone consists of fine-grained sands with a number of discontinuous silt and clay lenses. A regional interval with high clay content and cemented silt (USZ-LSZ Aquitard) separates the Garber Sandstone into two distinct hydrogeologic intervals. The aquitard is found at an approximate depth of 40 to 45 feet bgs.

The hydrogeology at FTA 2 also closely matches regional conditions. The unconfined USZ potentiometric surface coincides approximately with the Hennessey Group/Garber Sandstone (USZ sands) contact, generally within 8 feet of the contact in the Hennessey Group, and 7 to 15 feet bgs. A perched HWBZ exits approximately 1000 feet to the south of FTA 2. Groundwater elevations and monitoring well completion data are listed in Table 2.2. Figure 2.8 is a groundwater potentiometric map for the USZ based on data from September 1996 (Tinker AFB, 1996). Flow direction in the immediate vicinity of FTA 2 is generally towards the west, with local variations due to lithologic, topographic, or surface (tributary) features. The groundwater gradient in the USZ is approximately 0.0037 ft/ft. The flow direction and gradient in the USZ are consistent with groundwater flow direction and gradient data observed in 1994 (IT, 1994). The base of the USZ is a layer of hard siltstone traceable across the area at a depth of approximately 40 to 45 feet bgs.

The top of the LSZ coincides approximately with the base of the USZ-LSZ aquitard at a depth of approximately 50 to 60 feet bgs. Where the LSZ potentiometric surface lies beneath the base of the USZ-LSZ aquitard, the LSZ is under unconfined conditions (Figure 2.7). Locally the LSZ may be confined where the USZ-LSZ aquitard dips



NOTES:

1. ABBREVIATIONS USED ON CROSS-SECTIONS:
   - HWBZ —> HENNESSEY WATER BEARING ZONE
   - USZ —> UPPER SATURATED ZONE
   - LSZ —> LOWER SATURATED ZONE
   - LLSZ —> LOWER-LOWER SATURATED ZONE
   - PZ —> PRODUCING ZONE
2. "X" WELL IDENTIFIER INDICATES THAT WELL WAS DRILLED, THEN PLUGGED AND ABANDONED.
3. "P" IDENTIFIER INDICATES DEEP PILOT HOLE DRILLED FOR GEOPHYSICAL LOGGING PURPOSES.

EXPLANATION

(4AA') CROSS-SECTION TIE POINT(S)

WELL IDENTIFICATION

WELL

WATER LEVEL ELEVATION (JULY, 1995)

SCREENED INTERVAL

GAMMA LOG

45.0' TOTAL DEPTH DRILLED

* DIGITIZED ANALOG GAMMA LOGS

HENNESSEY WATER BEARING ZONE

HWBZ POTENTIOMETRIC SURFACE

UPPER SATURATED ZONE

USZ POTENTIOMETRIC SURFACE

LOWER SATURATED ZONE

LSZ POTENTIOMETRIC SURFACE

PRODU

PZ PC

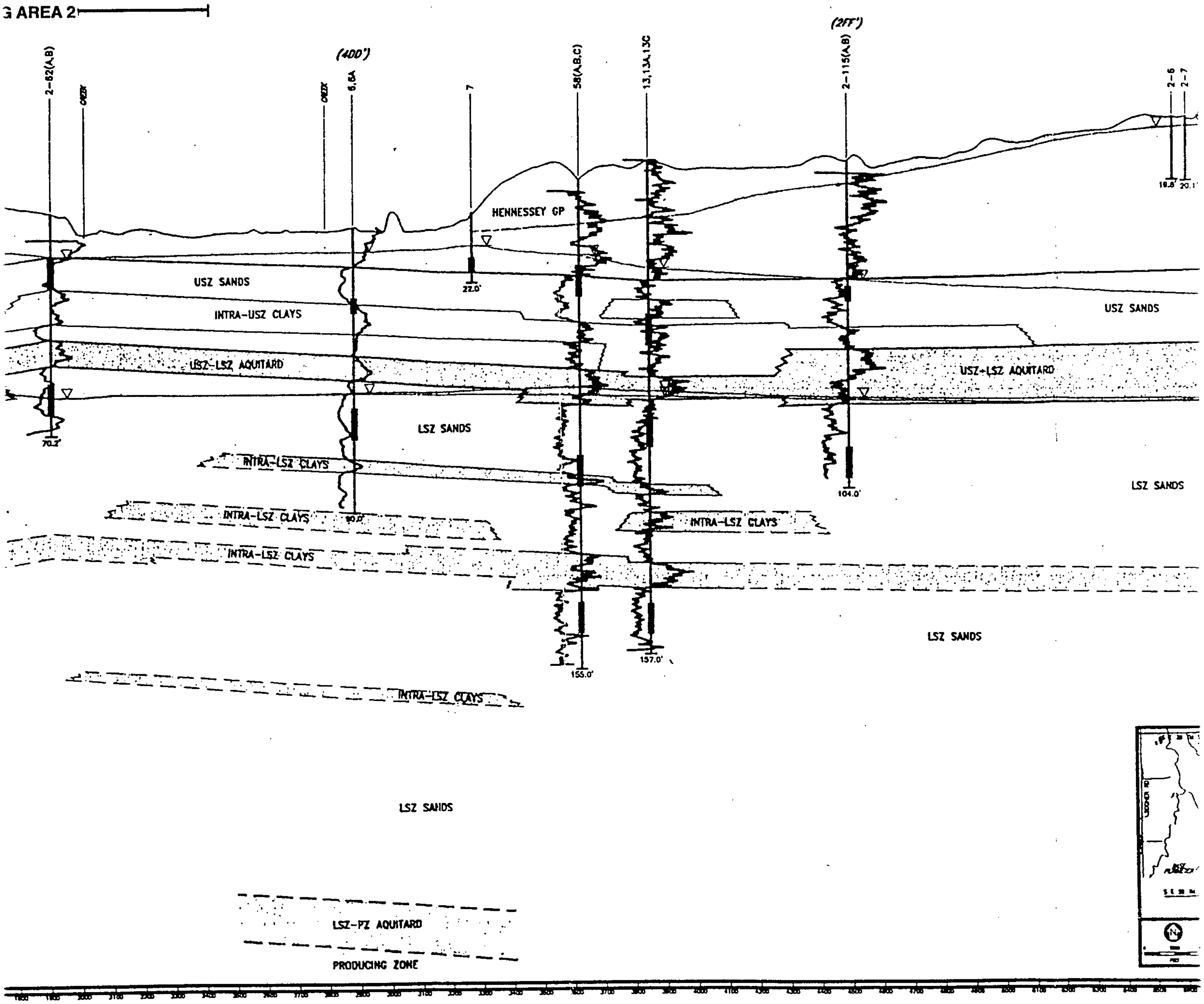
DRY W

HYDRO

LITHOL

NOTE:
POTENTIOMETRIC
BOUNDARIES, AN
DASHED WHERE I

Source: Tinker AFB, 1997.



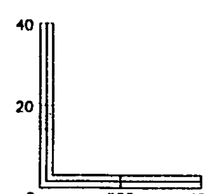
HENNESSEY WATER BEARING ZONE
HWBZ POTENTIOMETRIC SURFACE
UPPER SATURATED ZONE
USZ POTENTIOMETRIC SURFACE
LOWER SATURATED ZONE
LSZ POTENTIOMETRIC SURFACE

PRODUCING ZONE
PZ POTENTIOMETRIC SURFACE
DRY WELL
HYDROGEOLOGIC BOUNDARIES
LITHOLOGIC CONTACTS

NOTE:
POTENTIOMETRIC SURFACES, HYDROGEOLOGIC BOUNDARIES, AND LITHOLOGIC CONTACTS DASHED WHERE INFERRED.

HENNESSEY GROUP (GP)

GARBER-WELLINGTON AQUIFER
- USZ SANDS
- INTRA-USZ CLAYS
- USZ AQUITARD
- LSZ SANDS
- INTRA-LSZ CLAYS
- LSZ-PZ AQUITARD
- PRODUCING ZONE



SCALE IN FEET
VERTICAL EXAGGERATION = 10X

PA
EN

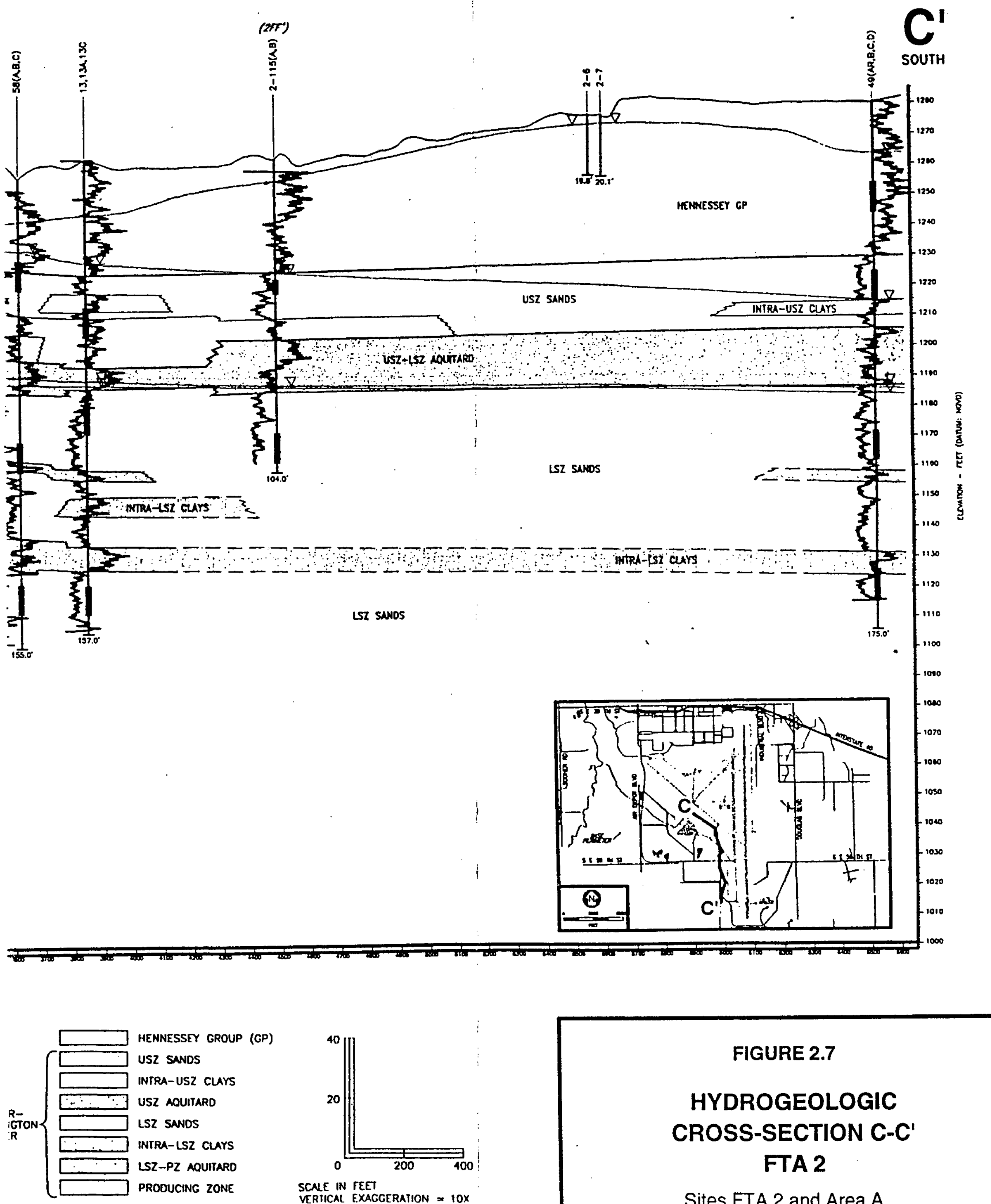


FIGURE 2.7

HYDROGEOLOGIC CROSS-SECTION C-C' FTA 2

Sites FTA 2 and Area A
RNA TS
Tinker AFB, Oklahoma

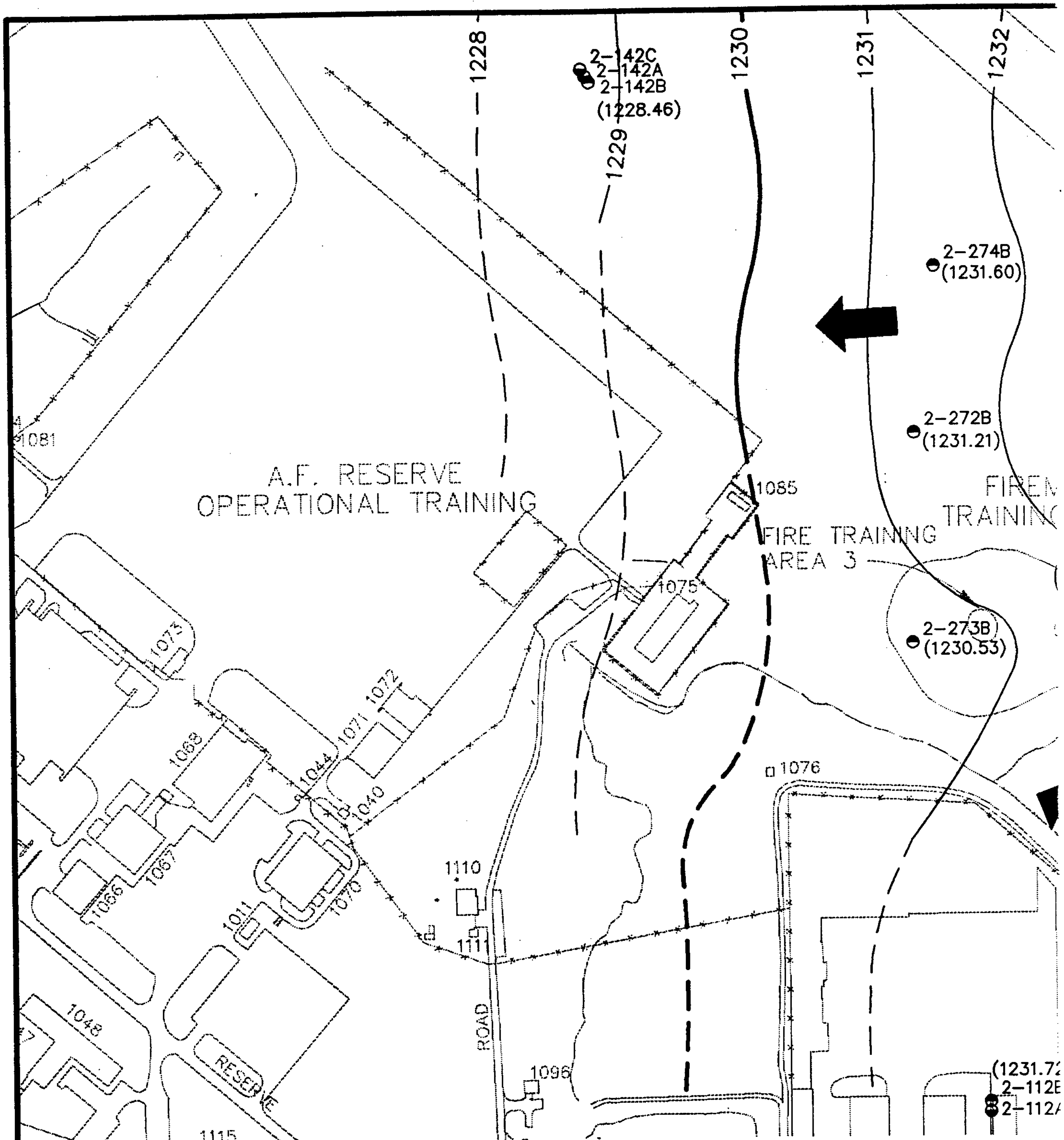
PARSONS ENGINEERING SCIENCE, INC.
Denver, Colorado

TABLE 2.2
MONITORING WELL SUMMARY AND
SEPTEMBER 1996 GROUNDWATER ELEVATIONS, FTA 2
SITES FTA-2 AND AREA A
RNA TS
TINKER AFB, OKLAHOMA

Well/Borehole Identification	Site Code	Aquifer Zone	Completion Date	Well Diameter (Inches)	Screened Interval (Feet bgs)[a/]	Elevation Datum (Feet msl)[b/]	Elevation Datum	Ground Surface Elevation	Survey Northing (State Plane)	Survey Easting (State Plane)	Depth to Water Sept. 1996 (ft btoc)[c/]	Elevation of Water Table - Sept. 1996 (Feet msl)
Monitoring Wells - Upper Saturated Zone												
2-62B	FT22	USZ	11/9/93	2.0	14-24	1245.94	Top PVC	1245.94	150444.52	2182140.56	14.24	1231.70
2-63B	FT22	USZ	11/8/93	2.0	18-23	1243.28	Top PVC	1243.28	150386.11	2182035.36	11.83	1231.45
2-64B	FT22	USZ	11/9/93	2.0	16-26	1245.59	Top PVC	1245.59	150467.40	2181967.76	13.88	1231.71
2-65B	FT22	USZ	11/5/93	2.0	37-47	1250.81	Top PVC	1250.81	150712.88	2182183.20	17.20	1233.61
2-167B	FT22	USZ	8/8/95	4.0	19-29	1250.70	Top PVC	1247.70	150539.81	2182408.35	16.07	1234.63
2-168B	FT22	USZ	8/8/95	4.0	10-20	1243.00	Top PVC	1240.10	150249.00	2181976.69	12.12	1230.88
2-271B	FT22	USZ	8/8/96	4.0	36-46	1252.13	Top PVC	1252.41	151494.42	2182196.43	18.55	1233.58
2-272B	FT22	USZ	8/9/96	4.0	25-35	1248.91	Top PVC	1249.38	150784.70	2181581.74	17.70	1231.21
2-273B	FT22	USZ	6/18/96	4.0	17-27	1238.42	Top PVC	1238.92	150351.11	2181576.36	7.89	1230.53
2-274B	FT22	USZ	7/25/96	4.0	37-42	1248.32	Top PVC	1248.77	151126.23	2181625.92	16.72	1231.60
1-67B	OT01	USZ	5/22/93	2.0	34-44	1264.15	Top PVC	NA[d/]	NA	NA	25.26	1238.82
2-142B	BW	USZ	5/19/95	4.0	32-42	1242.09	Top PVC	1242.45	NA	NA	13.56	1228.46
2-112B	LF15	USZ	1/20/95	4.0	30-40	1250.89	Top PVC	1247.65	NA	NA	19.10	1231.72
2-301B	LF15	USZ	6/17/96	4.0	16-26	1265.71	Top PVC	1263.19	150500.39	2176072.65	9.42	1256.29
2-302B	LF15	USZ	7/24/96	4.0	27-37	1249.15	Top PVC	1246.46	149491.80	2182106.79	16.91	1232.24
2-160B	ST07	USZ	6/5/95	4.0	5-15	1253.56	Top PVC	1250.99	NA	NA		
Monitoring Wells - Lower Saturated Zone												
2-62A	FT22	LSZ	11/29/93	2.0	54-64	1246.21	Top PVC	1246.21	150447.89	2182152.17	57.57	1188.64
2-63A	FT22	LSZ	11/23/93	2.0	53-63	1243.39	Top PVC	1243.39	150389.96	2182043.02	54.89	1188.50
2-64A	FT22	LSZ	11/22/93	2.0	56-66	1246.05	Top PVC	1246.05	150470.21	2181959.37	57.48	1188.57
2-65A	FT22	LSZ	11/19/93	2.0	66-76	1250.98	Top PVC	1250.98	150698.28	2182189.88	61.55	1189.43
1-67A	OT01	LSZ	5/22/93	2.0	75-85	1264.37	Top PVC	NA	NA	NA	71.05	1193.25
1-67C	OT01	LLSZ	5/22/93	2.0	109-119	1264.19	Top PVC	NA	NA	NA	71.07	1193.05
2-142A	BW	LSZ	5/19/95	4.0	72-82	1241.76	Top PVC	1242.30	NA	NA	52.98	1188.71
2-112A	LF15	LSZ	1/23/95	4.0	86-96	1251.41	Top PVC	1248.03	NA	NA	64.48	1186.86

[a/] feet bgs indicates elevation in feet below ground surface.
[b/] feet msl indicates elevation in feet above mean sea level.
[c/] btoc indicates depth measured below top of well casing.
[d/] NA indicates the data are not currently available.

L:\TINKER\WORKPLAN\FTA2\FT-2WELL.XLS (1/24/97)



LEGEND

2-142B — UPPER SATURATED ZONE MONITORING WELL LOCATION AND ID NUMBER

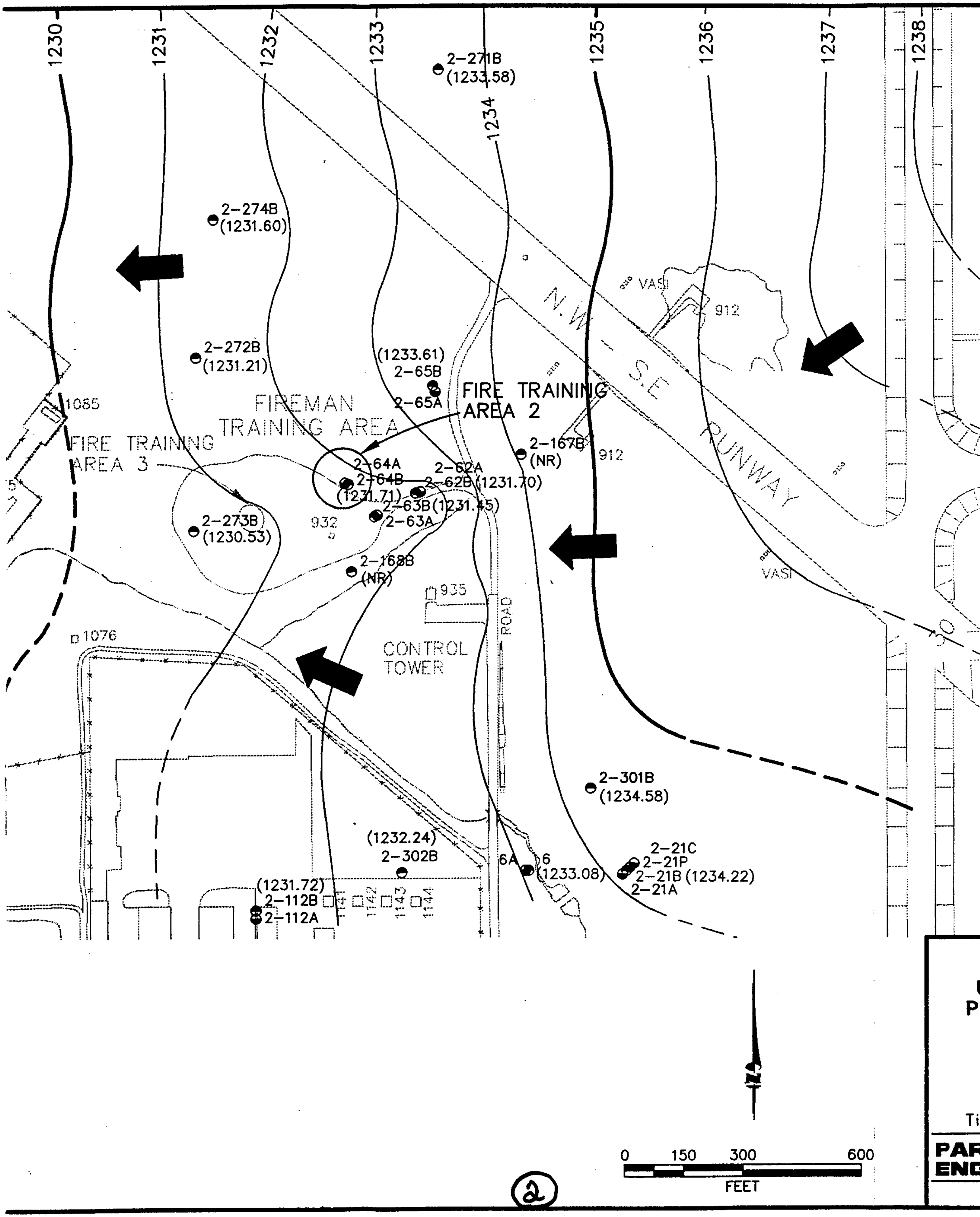
2-142A — LOWER SATURATED ZONE MONITORING WELL LOCATION AND ID NUMBER

DIRECTION OF GROUNDWATER FLOW

—1231— LINE OF EQUAL GROUNDWATER ELEVATION (FEET MSL), DASHED WHERE INFERRED

1

K:\AFCEE\729691\97DN0033, 03/04/97 at 07:41



1230
1231
1232
1233
1234
1235
1236
1237
1238
2-271B
(1233.58)
2-274B
(1231.60)
2-272B
(1231.21)
(1233.61)
2-65B
2-65A
FIRE TRAINING
AREA 2
FIREMAN
TRAINING AREA
FIRE TRAINING
AREA 3
1085
2-64A
2-64B
(1231.71)
2-62A
2-62B (1231.70)
2-63B (1231.45)
2-63A
2-273B
(1230.53)
932
2-167B
(NR)
912
VASI
N.W. - S.E RUNWAY
2-168B
(NR)
935
ROAD
1076
CONTROL
TOWER
2-301B
(1234.58)
(1232.24)
2-302B
6A
6
(1233.08)
2-21C
2-21P
2-21B (1234.22)
2-21A
(1231.72)
2-112B
2-112A
1141
1142
1143
1144
0
150
300
600
FEET

Tin

PAR
ENG

2

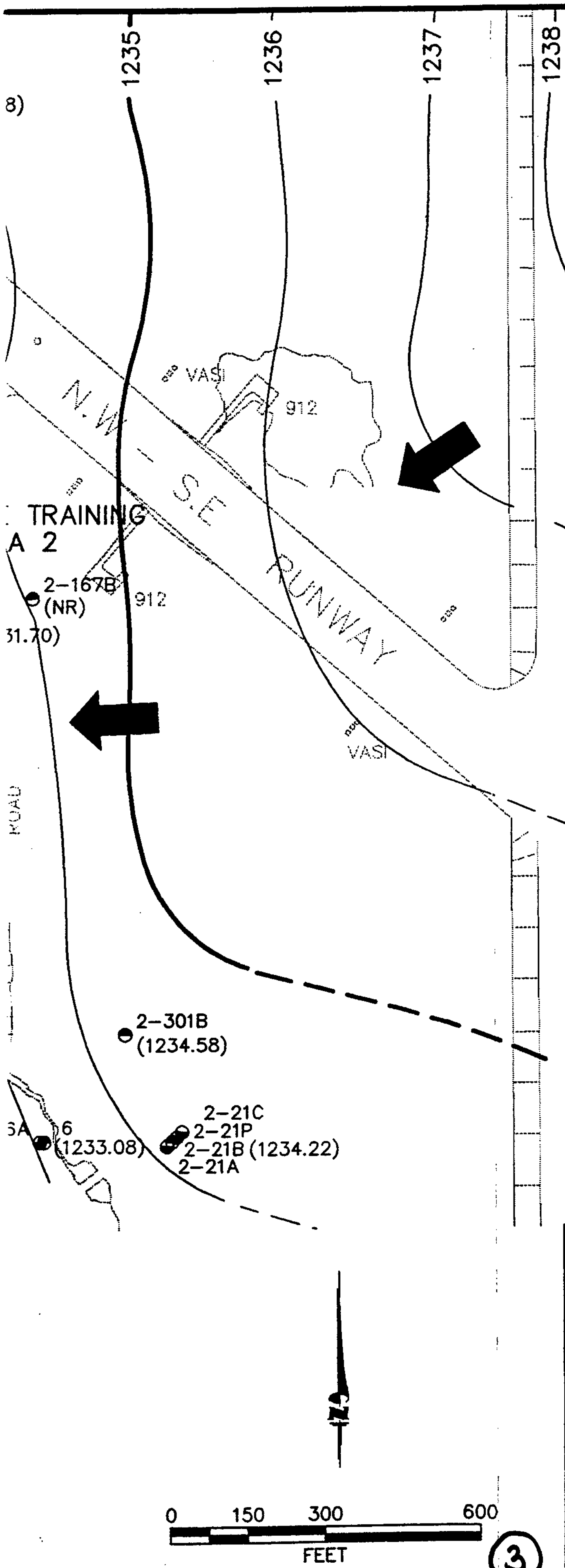


FIGURE 2.8

UPPER SATURATED ZONE POTENTIOMETRIC SURFACE SEPTEMBER 1996 FTA 2

Sites FTA 2 and Area A
RNA TS
Tinker AFB, Oklahoma City, Oklahoma

PARSONS ENGINEERING SCIENCE, INC.
Denver, Colorado

3

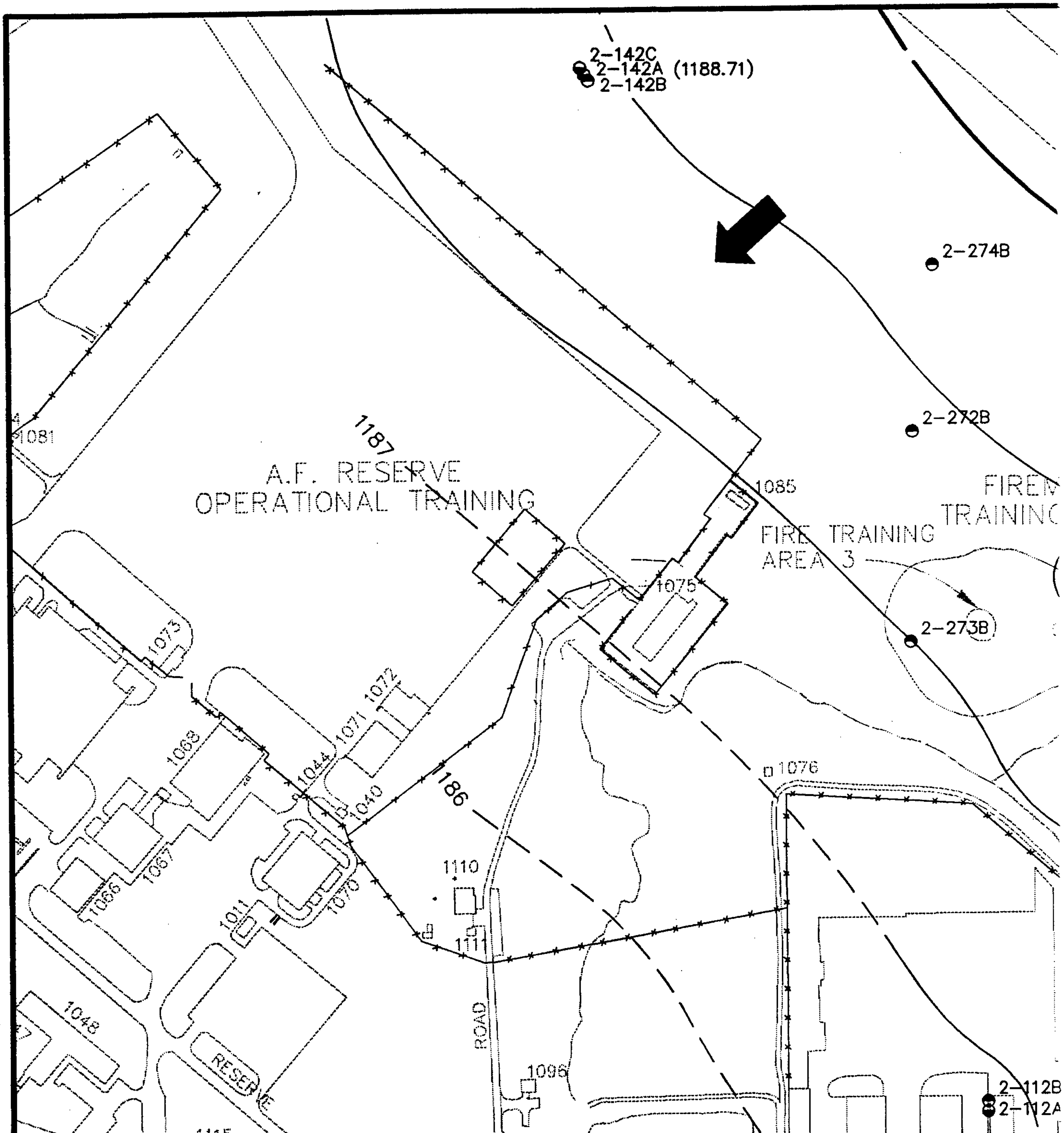
beneath the LSZ potentiometric surface. Figure 2.9 is a groundwater potentiometric surface map for the LSZ based on data from September 1996 (Tinker AFB 1996 database). Groundwater flow in the LSZ is towards the southwest at an approximate gradient of 0.0023 ft/ft. The flow direction and gradient in the USZ are consistent with groundwater flow direction and gradient data observed in 1994 (IT, 1994).

Available geological boring logs, monitoring well completion records, and slug test data for FTA 2 are included in Appendix B.

2.1.2.4 Area A Geology and Hydrogeology

The geology at Area A matches the description of the regional geology. Area A hydrogeologic cross-sections D-D' (Figure 2.10) and E-E' (Figure 2.11) illustrate the stratigraphy through the center of the site perpendicular (D-D') and parallel (E-E') to the direction of groundwater flow. The Garber Sandstone is present from ground surface to the maximum depth drilled (86 feet bgs). Approximately 10 to 20 feet of clay, silty clay, and clayey silt (intra-USZ clays) are present at the surface. Beneath this clay unit is approximately 15 to 28 feet of fine-grained sands, with discontinuous silt and clay lenses peripheral to the area immediately beneath the Area A service station. A regional interval with high clay content and cemented silt (USZ-LSZ Aquitard) separates the Garber Sandstone into two distinct hydrogeologic intervals. This interval is present at an approximate depth of 35 feet bgs. The aquitard at Area A is approximately 5 to 7 feet thick, and overlies fine-grained sands and intra-LSZ clays and clayey silts.

The hydrogeology at Area A also closely matches regional conditions. The USZ groundwater surface is approximately 10 to 20 feet bgs within USZ sands. Groundwater in the USZ generally is under unconfined conditions, but may be locally confined immediately beneath the Area A service station where the USZ potentiometric surface lies within intra-USZ clays. Groundwater elevations and monitoring well



LEGEND

2-142B — UPPER SATURATED ZONE MONITORING WELL LOCATION AND ID NUMBER

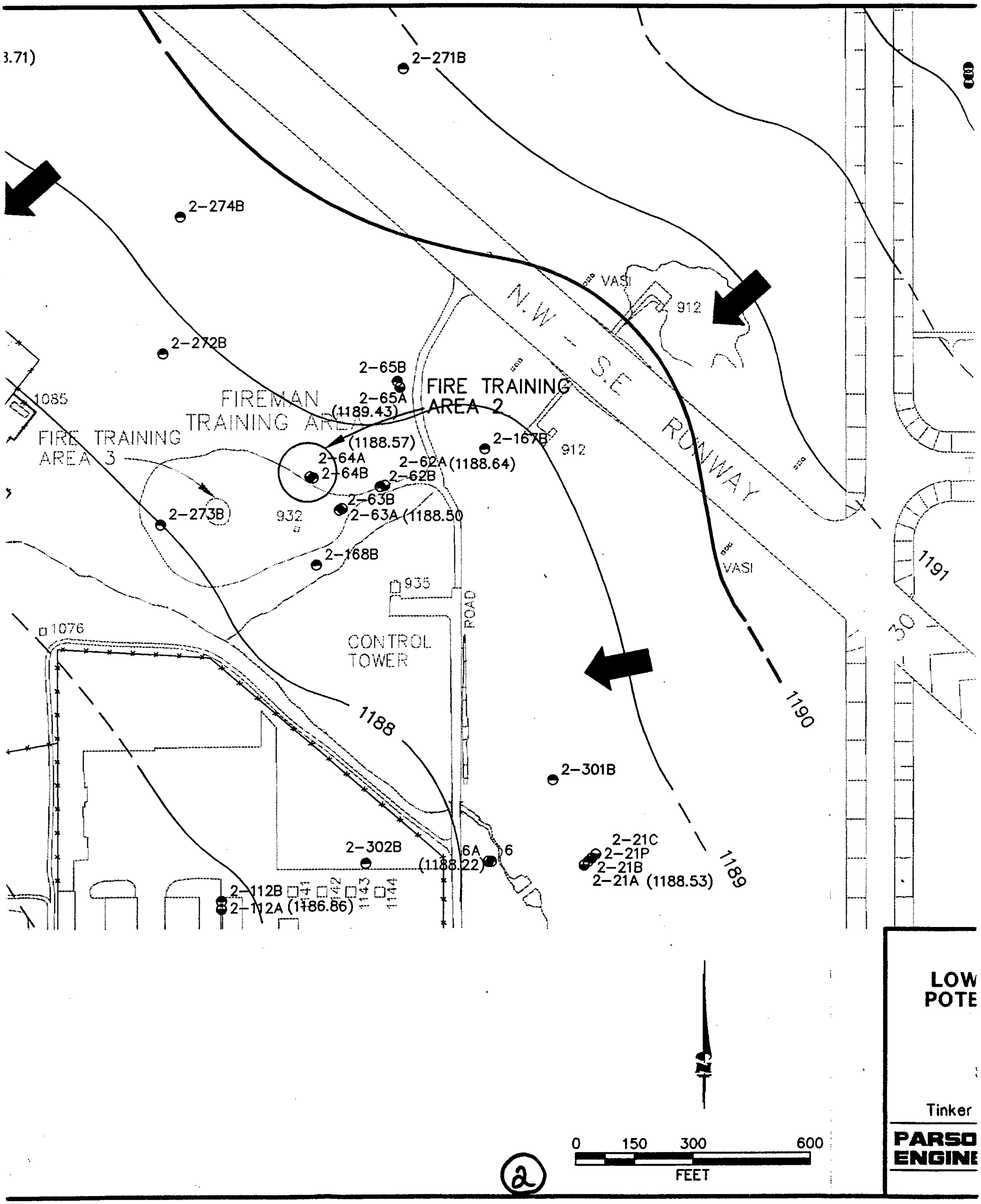
2-142A — LOWER SATURATED ZONE MONITORING WELL LOCATION AND ID NUMBER

DIRECTION OF GROUNDWATER FLOW

1188 — LINE OF EQUAL GROUNDWATER ELEVATION (FEET MSL), DASHED WHERE INFERRED

1

K:\AFCEE\729691\97DN0034, 03/04/97 at 08:00



3.71)
2-271B
2-274B
2-272B
2-65B
2-65A
(1189.43)
FIRE TRAINING
AREA 2
FIREMAN
TRAINING AREA
1085
FIRE TRAINING
AREA 3
(1188.57)
2-64A
2-64B
2-62A (1188.64)
2-62B
2-63B
2-63A (1188.50
2-273B
932
2-168B
2-167B
912
VASI
N.W. - S.E. RUNWAY
935
ROAD
CONTROL
TOWER
1076
1188
1189
1190
1191
30
2-301B
2-21C
2-21P
2-21B
2-21A (1188.53)
2-302B
6A
6
(1188.22)
2-112B
2-112A (1186.86)
1141
1142
1143
1144
0
150
300
600
FEET
LOW
POTE
Tinker
PARSO
ENGINE

2

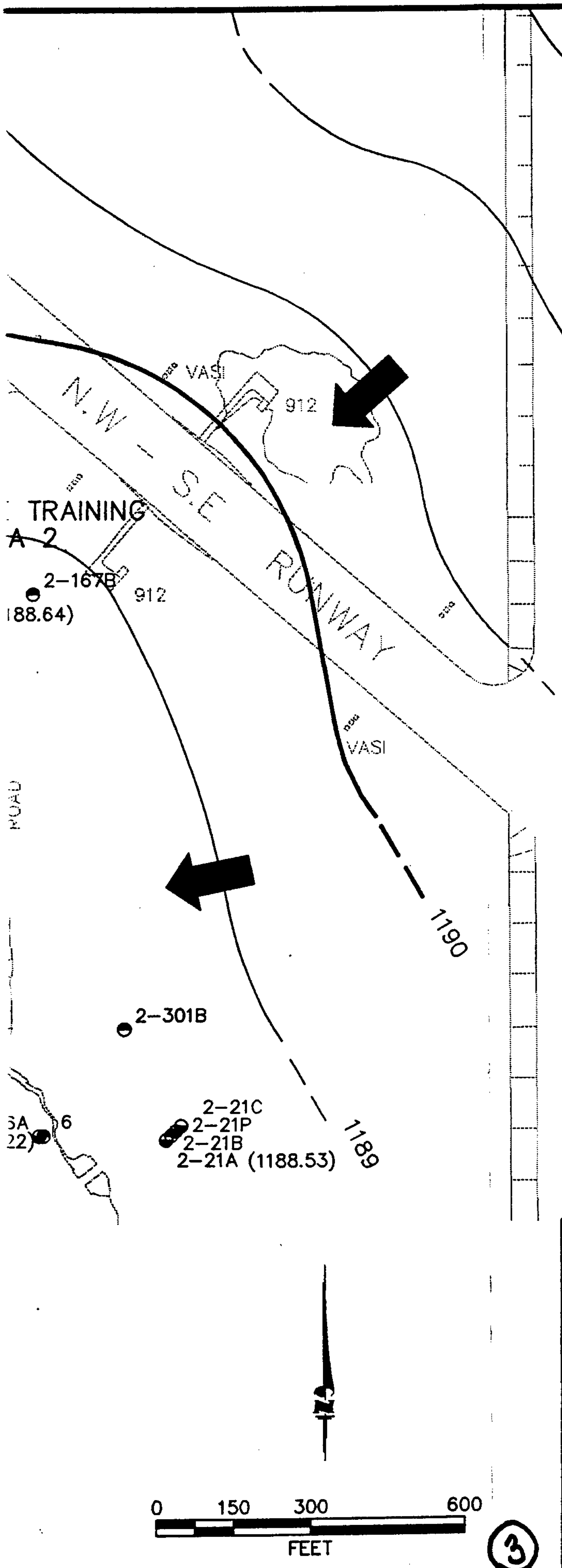


FIGURE 2.9

LOWER SATURATED ZONE POTENTIOMETRIC SURFACE SEPTEMBER 1996 FTA 2

Sites FTA 2 and Area A
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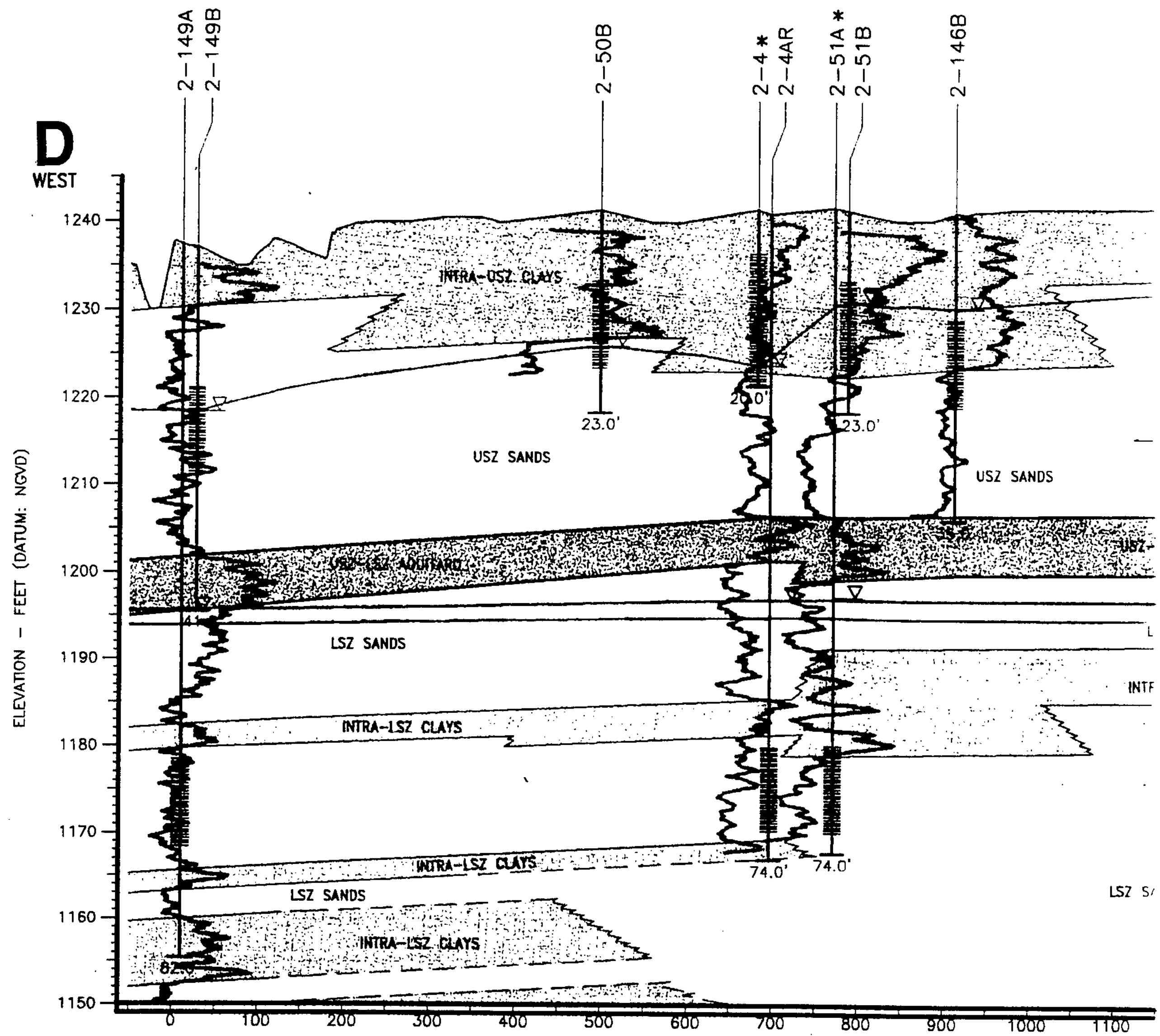
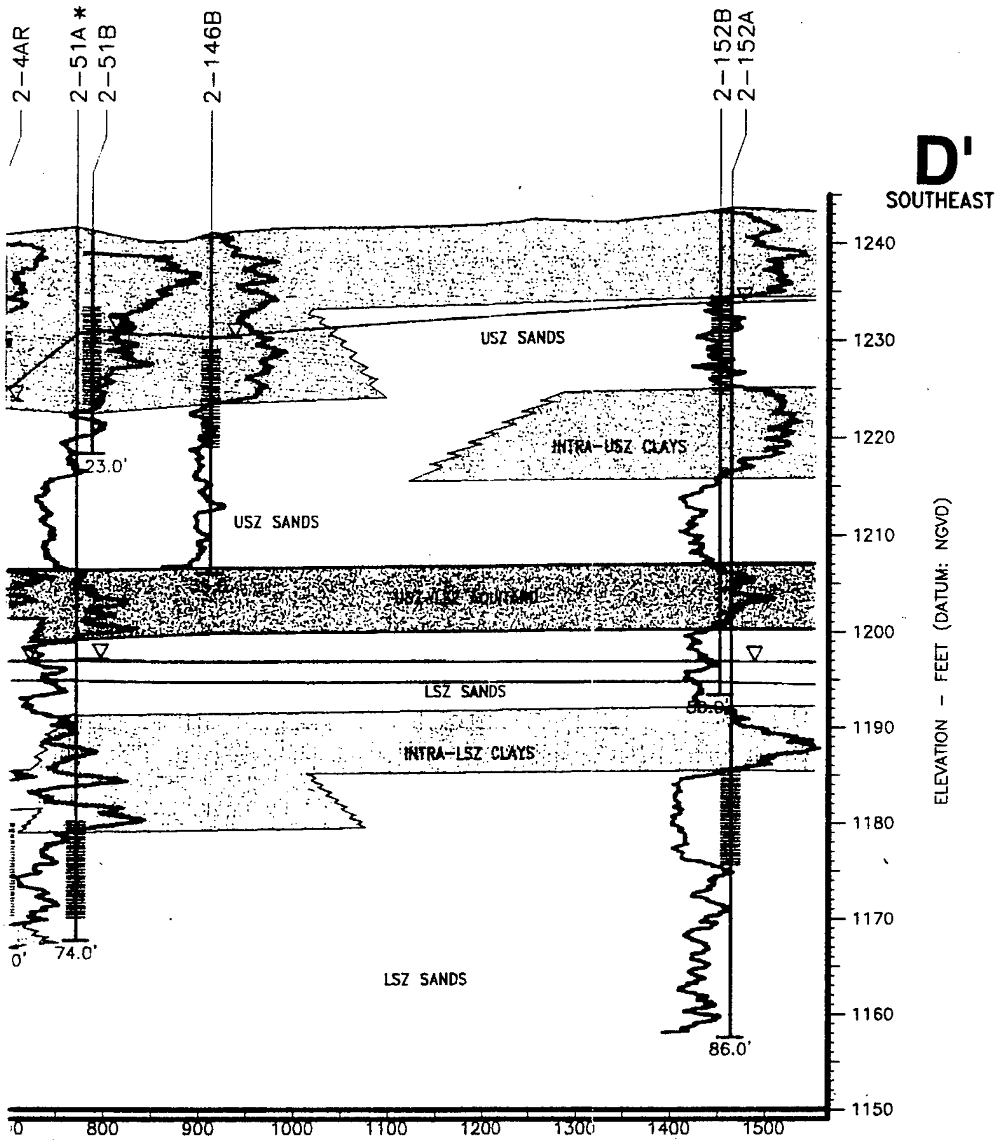


Source: IT, 1996.

NOTE:

1. ABBREVIATIONS USED ON CROSS-SECTIONS;
   USZ ——> UPPER SATURATED ZONE
   LSZ ——> LOWER SATURATED ZONE
   LLSZ —> LOWER-LOWER SATURATED ZONE
   PZ ——> PRODUCING ZONE

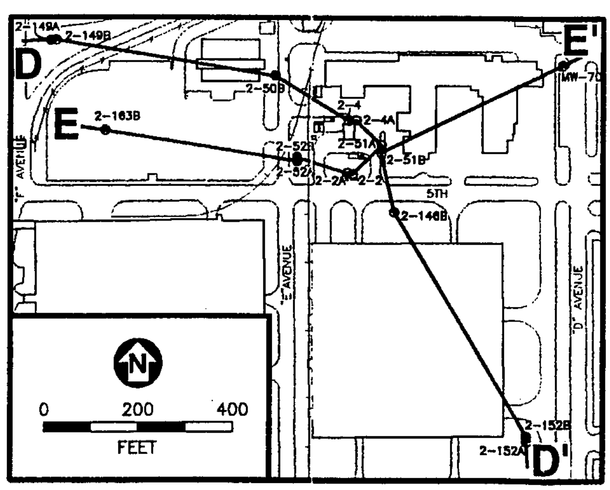


EXPLANATION

- D — WELL IDENTIFICATION
- WELL
- WATER LEVEL ELEVATION (JULY, 1995)
- SCREENED INTERVAL
- GAMMA LOG
- 45.0' TOTAL DEPTH DRILLED
- * DIGITIZED ANALOG GAMMA LOGS
- UPPER SATURATED ZONE
- USZ POTENTIOMETRIC SURFACE
- LOWER SATURATED ZONE
- LSZ POTENTIOMETRIC SURFACE
- HYDROGEOLOGIC BOUNDARIES (DASHED WHERE INFERRED)
- LITHOLOGIC CONTACTS (DASHED WHERE INFERRED)

NOTE:
POTENTIOMETRIC SURFACES, HYDROGEOLOGIC BOUNDARIES, AND LITHOLOGIC CONTACTS DASHED WHERE INFERRED.

GARBER-WELLINGTON AQUIFER
- USZ SANDS
- INTRA-USZ CLAYS
- USZ-LSZ AQUITARD
- LSZ SANDS
- INTRA-LSZ CLAYS



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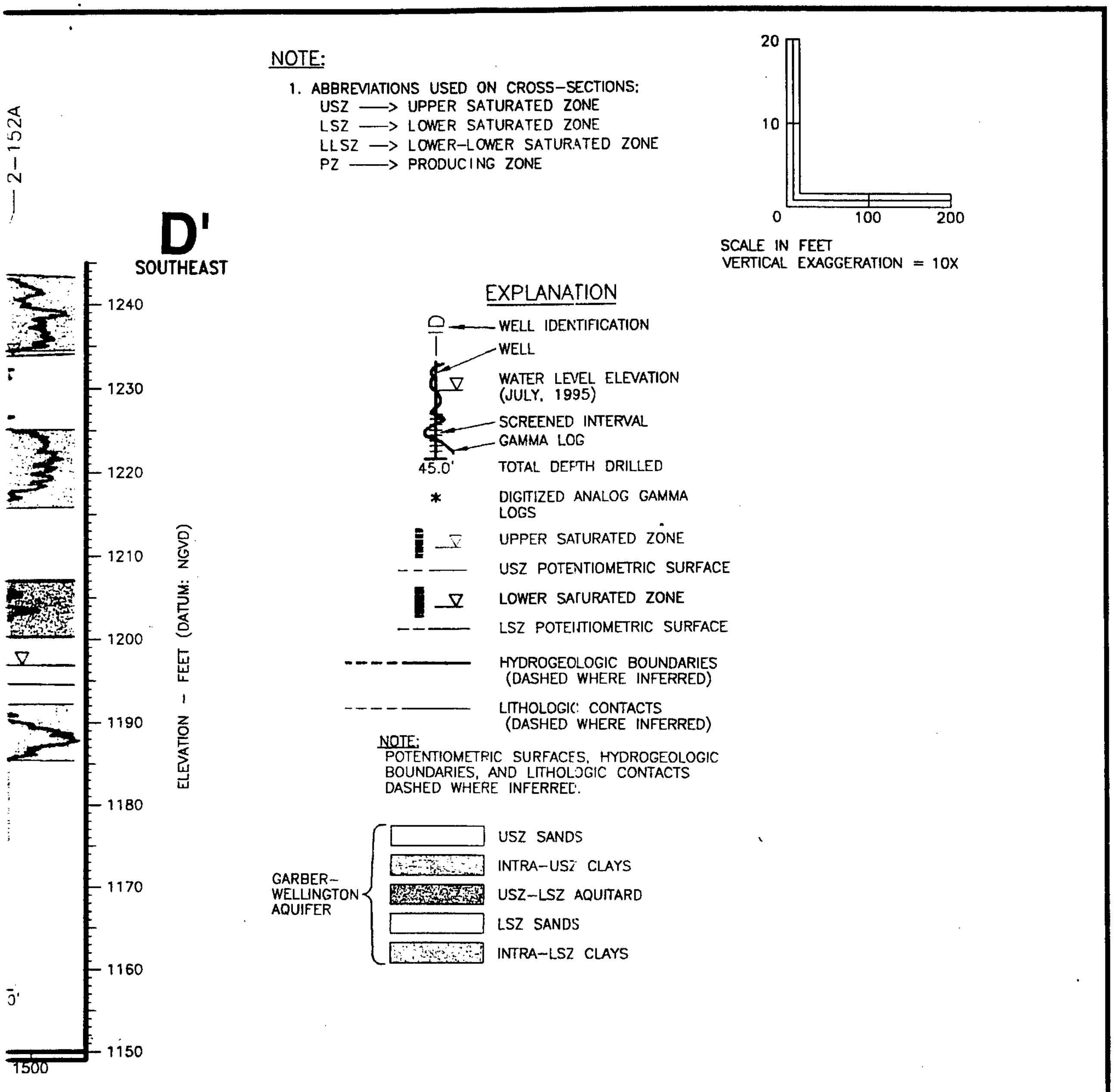

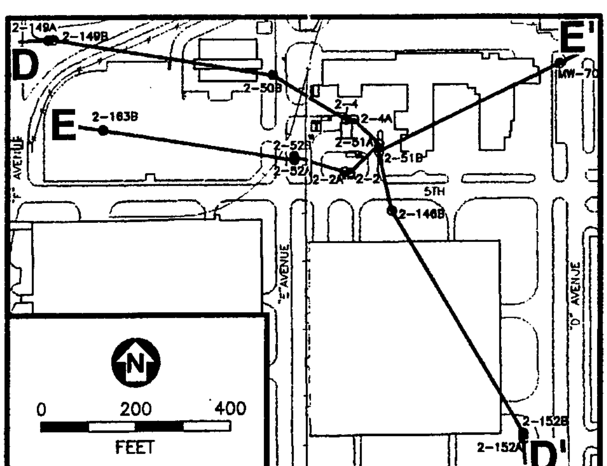

FIGURE 2.10

HYDROGEOLOGIC CROSS-SECTION D-D' AREA A SERVICE STATION

Sites FTA 2 and Area A
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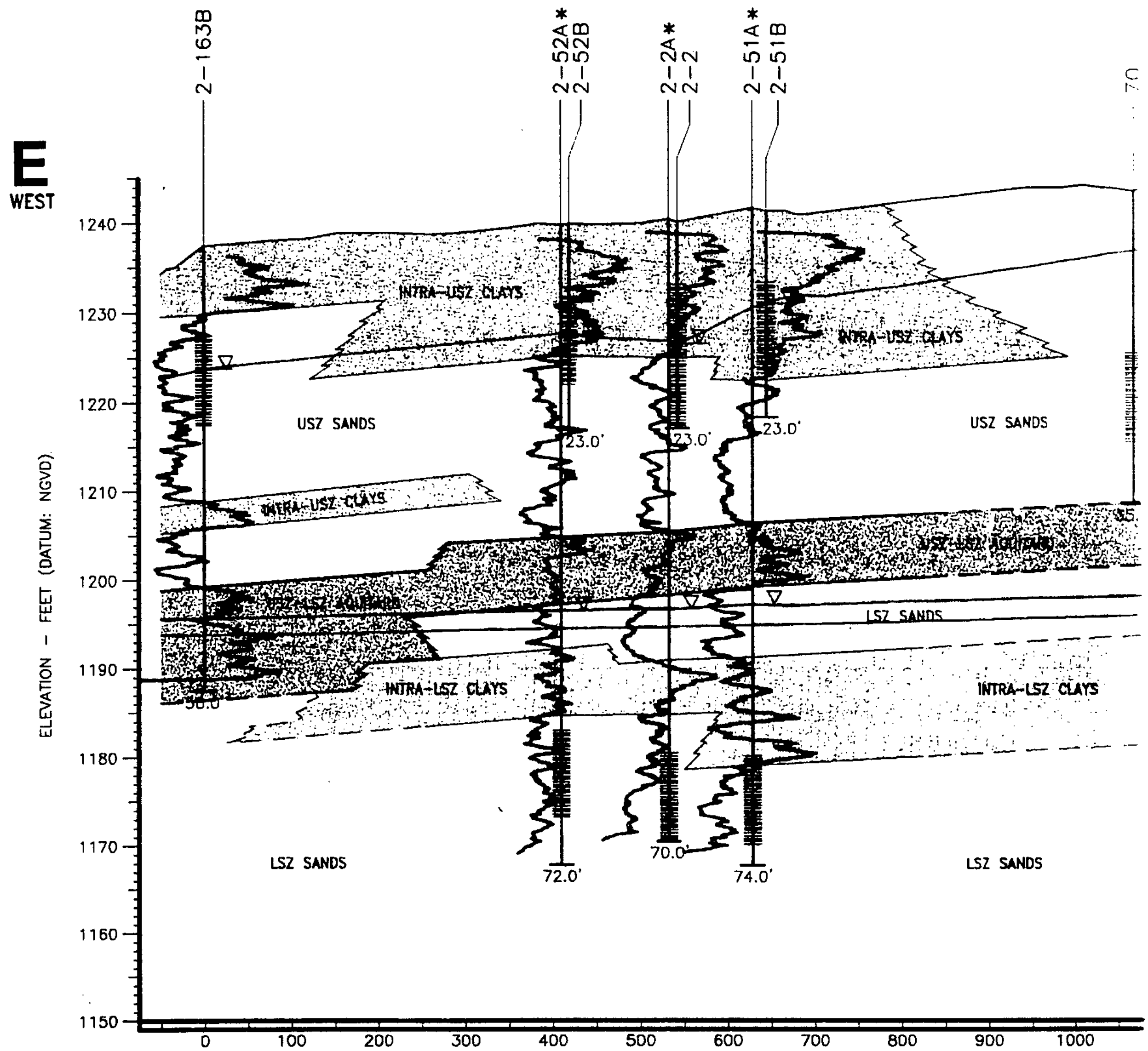
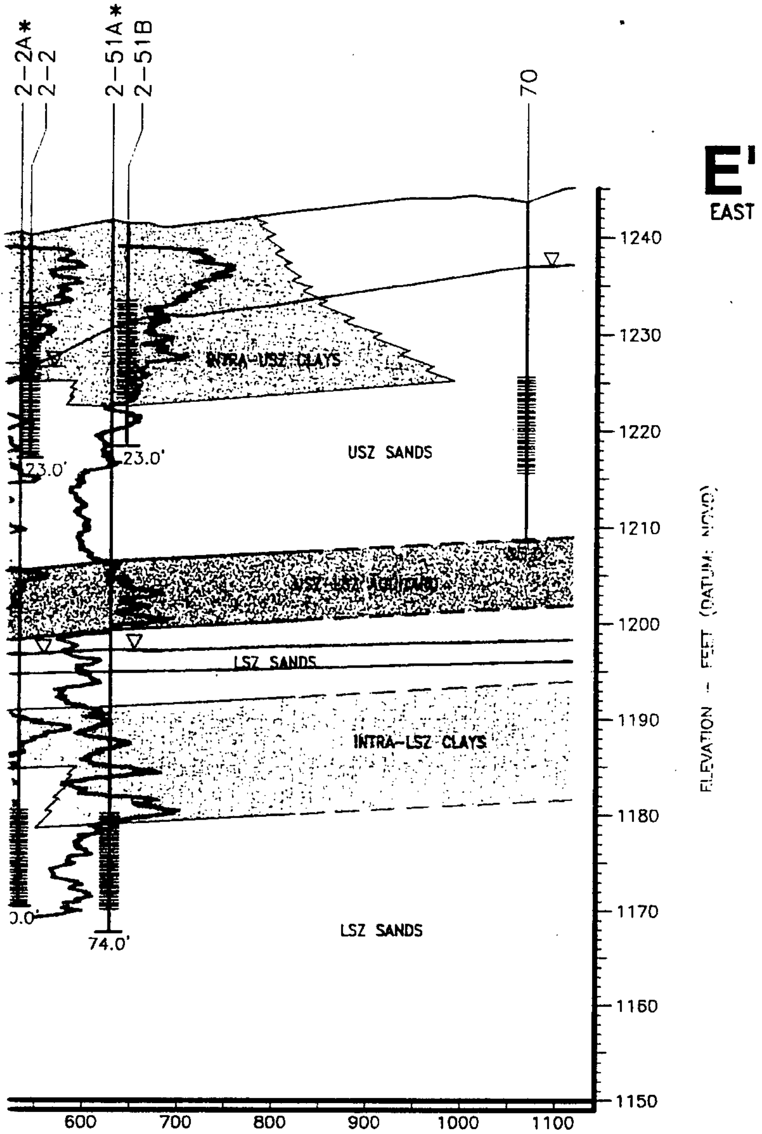
Denver, Colorado

3



Source: IT, 1996.



NOTE:

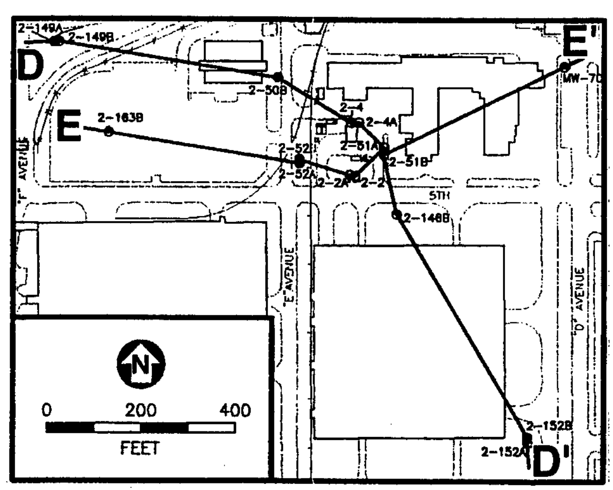
1. ABBREVIATIONS USED ON CROSS-SECTIONS;
   USZ ——> UPPER SATURATED ZONE
   LSZ ——> LOWER SATURATED ZONE
   LLSZ ——> LOWER-LOWER SATURATED ZON
   PZ ——> PRODUCING ZONE

EXPLANATION

ID — WELL IDENTIFICATION
WELL
WATER LEVEL ELEVATION (JULY, 1995)
SCREENED INTERVAL
GAMMA LOG
45.0' TOTAL DEPTH DRILLED
* DIGITIZED ANALOG GAMMA LOGS
UPPER SATURATED ZONE
USZ POTENTIOMETRIC SUR
LOWER SATURATED ZONE
LSZ POTENTIOMETRIC SUR
HYDROGEOLOGIC BOUNDAR (DASHED WHERE INFERRE
LITHOLOGIC CONTACTS (DASHED WHERE INFERRE

NOTE:
POTENTIOMETRIC SURFACES, HYDROGEOLO BOUNDARIES, AND LITHOLOGIC CONTACTS DASHED WHERE INFERRED.

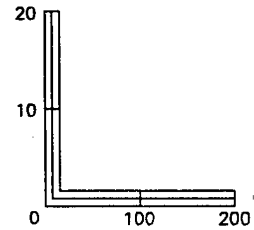
GARBER-WELLINGTON AQUIFER
- USZ SANDS
- INTRA-USZ CLAYS
- USZ-LSZ AQUITARD
- LSZ SANDS
- INTRA-LSZ CLAYS



PA
EN

NOTE:

1. ABBREVIATIONS USED ON CROSS-SECTIONS;
   - USZ ——> UPPER SATURATED ZONE
   - LSZ ——> LOWER SATURATED ZONE
   - LLSZ ——> LOWER-LOWER SATURATED ZONE
   - PZ ——> PRODUCING ZONE



SCALE IN FEET
VERTICAL EXAGGERATION = 10X

EXPLANATION

- WELL IDENTIFICATION
- WELL
- WATER LEVEL ELEVATION (JULY, 1995)
- SCREENED INTERVAL
- GAMMA LOG
- 45.0' TOTAL DEPTH DRILLED
- * DIGITIZED ANALOG GAMMA LOGS
- UPPER SATURATED ZONE
- USZ POTENTIOMETRIC SURFACE
- LOWER SATURATED ZONE
- LSZ POTENTIOMETRIC SURFACE
- HYDROGEOLOGIC BOUNDARIES (DASHED WHERE INFERRED)
- LITHOLOGIC CONTACTS (DASHED WHERE INFERRED)

NOTE:
POTENTIOMETRIC SURFACES, HYDROGEOLOGIC BOUNDARIES, AND LITHOLOGIC CONTACTS DASHED WHERE INFERRED.

GARBER-WELLINGTON AQUIFER:
- USZ SANDS
- INTRA-USZ CLAYS
- USZ-LSZ AQUITARD
- LSZ SANDS
- INTRA-LSZ CLAYS

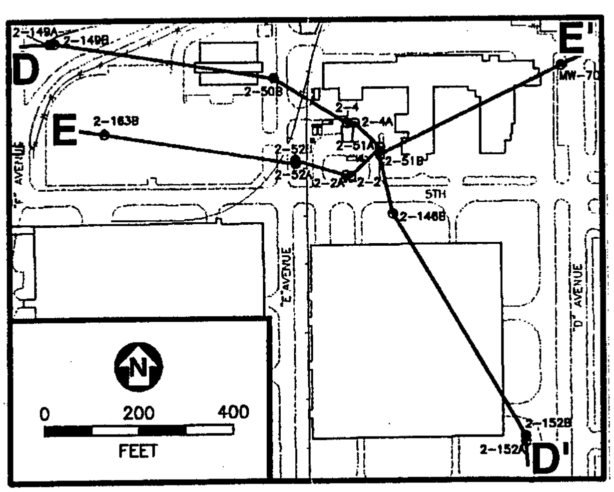


FIGURE 2.11

HYDROGEOLOGIC CROSS-SECTION E-E' AREA A SERVICE STATION

Sites FTA 2 and Area A
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Tinker AFB, Oklahoma

PARSONS ENGINEERING SCIENCE, INC.
Denver, Colorado

completion data are listed in Table 2.3. Figure 2.12 is a groundwater elevation contour map for the USZ based on data from September 1996 (Tinker AFB 1996 database). Flow direction in the immediate vicinity of Area A is generally northwest to southwest, and predominantly west beneath the Area A service station. A local area of low groundwater elevations is present immediately beneath the Area A service station, coinciding with a three-well product recovery system. Other local variations in USZ flow direction may be due to lithologic, topographic, or surface features. The groundwater gradient in the USZ is approximately 0.007 to 0.025 ft/ft. The flow direction and gradient in the USZ are consistent with groundwater flow direction and gradient data observed in July 1995 (IT, 1996). Hydraulic conductivity averages 1.4 feet per day (ft/day), as measured in three USZ monitoring wells by IT (1996). The base of the USZ is a layer of hard siltstone traceable across the area at a depth of approximately 35 feet bgs.

Groundwater in the LSZ is present approximately 2 to 4 feet beneath the base of the USZ-LSZ aquitard at a depth of approximately 45 feet bgs, indicating unconfined conditions (Figure 2.10). To the west of Area A the LSZ may be confined where the USZ-LSZ aquitard dips beneath the LSZ potentiometric surface (Figure 2.11). Figure 2.13 is a groundwater elevation contour map for the LSZ based on data from September 1996 (Tinker AFB 1996 database). Groundwater flow in the LSZ is towards the west and southwest at an approximate gradient of 0.003 ft/ft. Hydraulic conductivity averages 1.6 feet per day (ft/day), as measured in four LSZ monitoring wells by IT (1996). The flow direction and gradient in the USZ are consistent with groundwater flow direction and gradient data observed in July 1995 (IT, 1996).

Available geological boring logs, monitoring well completion records, and slug test data for Area A are included in Appendix C.

TABLE 2.3
MONITORING WELL SUMMARY AND
SEPTEMBER 1996 GROUNDWATER ELEVATIONS, AREA A
SITES FTA 2 AND AREA A
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Well/Borehole Identification	Site Code	Aquifer Zone	Completion Date	Well Diameter (Inches)	Screened Interval (Feet bgs)[a]	Elevation Datum (Feet msl)[b]	Elevation Datum	Ground Surface Elevation	Survey Northing (State Plane)	Survey Easting (State Plane)	Depth to Water Sept. 1996 (ft btoc)[c]	Depth Product (ft btoc) Sept. 96	Elevation of Water Table - Sept. 1996[d] (Feet msl)
Monitoring Wells - Upper Saturated Zone													
2-2	ST33	USZ	5/20/91	4.0	7-23	1241.99	Top PVC	1240.181	158257.415	2180366.34	12.02	--[e]	1229.90
2-3	ST33	USZ	5/23/91	4.0	9.5-24.5	1242.34	Top PVC	1240.96	158378.687	2180180.29	14.22	--	1228.05
2-4	ST33	USZ	5/20/91	4.0	5-20	1243.16	Top PVC	1241.49	158368.054	2180358.922	13.61	12.64	1230.33
2-50B	ST33	USZ	10/26/93	2.0	8.0-17.85	1241.30	Top PVC	1241.38	158461.79	2180201.11	14.40	13.69	1227.47
2-51B	ST33	USZ	10/21/93	2.0	8.0-17.85	1241.29	Top PVC	1241.45	158301.11	2180427.53	7.43	--	1233.86
2-52B	ST33	USZ	10/25/93	2.0	8.1-17.85	1241.81	Top PVC	1239.95	158292.47	2180247.69	12.62	--	1229.19
2-163B	ST33	USZ	6/1/95	4.0	10-20	1237.10	Top PVC	1237.50	158347.12	2179842.46	13.54	--	1223.49
2-164B	ST33	USZ	6/2/95	4.0	15-25	1239.90	Top PVC	1236.22	158168.82	2179771.82	14.40	--	1225.43
2-165B	ST33	USZ	6/7/95	4.0	9-19	1223.60	Top PVC	1224.15	158763.17	2179903.68	4.72	--	1218.81
2-166B	ST33	USZ	6/7/95	4.0	13-23	1244.97	Top PVC	1242.38	158641.13	2180207.24	18.16	--	1226.74
2-173B	ST33	USZ	6/14/95	4.0	12-22	1240.41	Top PVC	1237.94	158062.21	2180186.91	13.27	--	1227.07
2-264B	ST33	USZ	6/12/96	4.0	19-29	1234.86	Top PVC	1235.08	158467.86	2179427.90	15.55	--	1219.31
2-265B	ST33	USZ	6/12/96	4.0	20-30	1236.63	Top PVC	1234.13	158291.51	2179373.38	15.83	--	1220.80
70	PRM	USZ	10/29/87	4.0	17.8-28.4	1246.23	Top PVC	1243.576	158485.40	2180809.30	9.30	--	1236.86
2-146B	PRM	USZ	6/13/95	4.0	12-22	1240.70	Top PVC	1241.16	158179.06	2180454.43	10.28	--	1230.35
2-148B	PRM	USZ	5/20/95	4.0	15-25	1250.12	Top PVC	1247.46	NA[f]	NA	8.71	--	1241.34
2-149B	PRM	USZ	6/7/95	4.0	16-26	1236.55	Top PVC	1237.08	158535.20	2179737.35	18.28	--	1218.20
2-150B	PRM	USZ	5/10/95	4.0	27-37	1234.03	Top PVC	1231.40	NA	NA	NA	--	NA
2-145B	BW	USZ	6/14/95	4.0	11-21	1242.75	Top PVC	1243.28	158576.19	2180541.42	NR	--	NR
2-152B	BW	USZ	5/18/95	4.0	9-19	1246.06	Top PVC	1243.46	NA	NA	13.05	--	1232.94
Monitoring Wells - Lower Saturated Zone													
2-2A	ST33	LSZ	11/24/93	2.0	60.0-70.0	1242.96	Top PVC	1240.51	158259.23	2180356.15	47.06	--	1195.90
2-4A	ST33	LSZ	12/29/93	2.0	61.0-70.0	1240.81	Top PVC	1240.98	158368.78	2180374.66	NR	--	NR
2-51A	ST33	LSZ	12/27/93	2.0	61.6-71.6	1241.65	Top PVC	1241.77	158317.01	2180427.68	45.23	--	1196.42
2-52A	ST33	LSZ	11/10/93	2.0	56.8-66.5	1241.98	Top PVC	1239.83	158283.58	2180247.93	46.26	--	1195.72
2-148A	PRM	LSZ	5/11/95	4.0	65-75	1250.11	Top PVC	1247.45	NA	NA	50.80	--	1199.24
2-149A	PRM	LSZ	6/5/95	4.0	59-69	1236.72	Top PVC	1237.39	158534.34	2179725.83	42.38	--	1194.27
2-152A	BW	LSZ	5/18/95	4.0	58-68	1246.36	Top PVC	1243.63	NA	NA	50.44	--	1195.85

a/ feet bgs indicates elevation in feet below ground surface.
b/ feet msl indicates elevation in feet above mean sea level.
c/ btoc indicates depth measured below top of well casing.
d/ Groundwater elevation corrected for the presence of free product using a product specific gravity of 0.80.
e/ -- indicates no measurable amount of free product present.
f/ NA indicates the data are not currently available.

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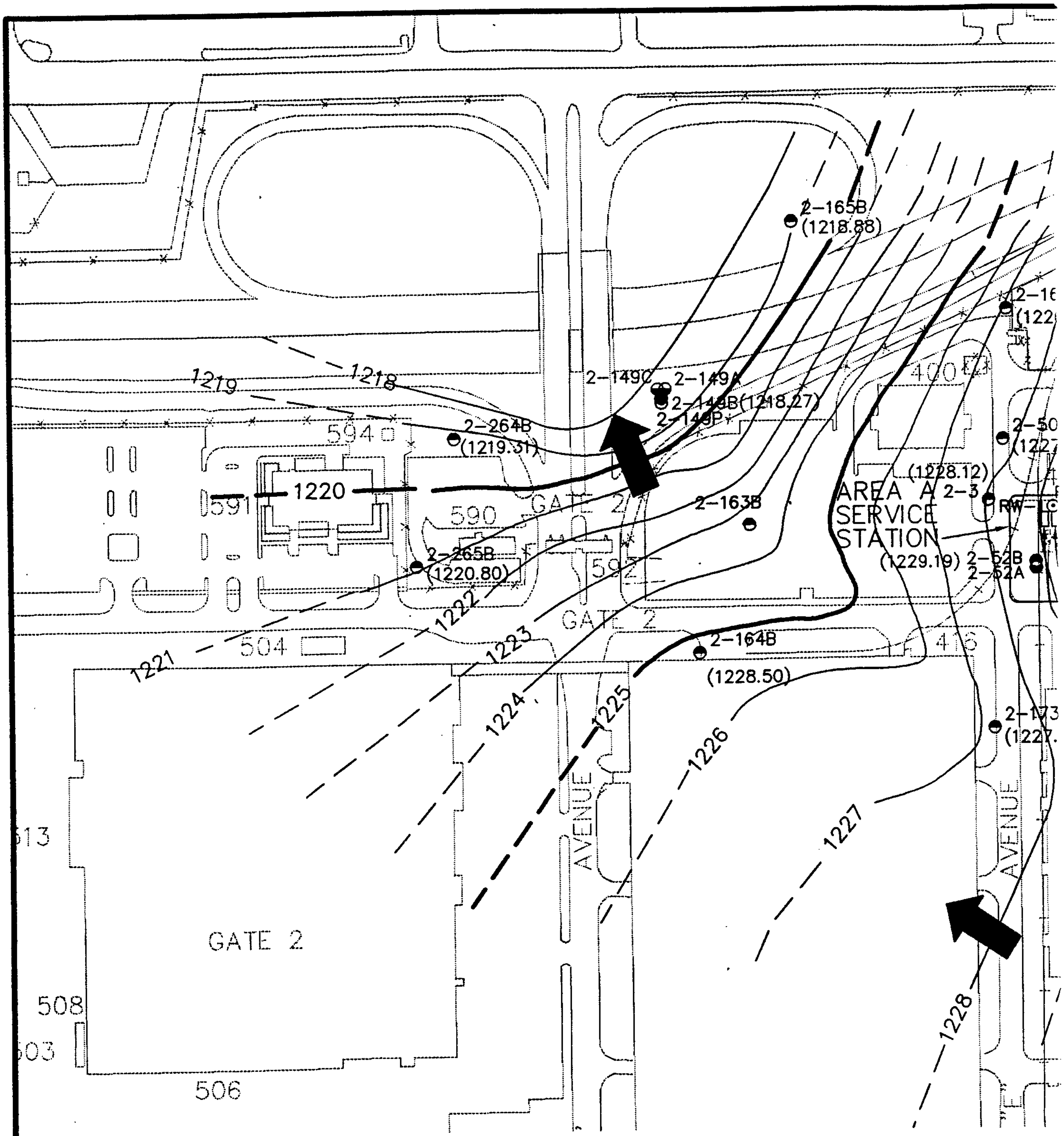

LEGEND

2-165B	UPPER SATURATED ZONE MONITORING WELL LOCATION AND ID NUMBER	DIRECTION OF GROUNDWATER FL
2-2A	LOWER SATURATED ZONE MONITORING WELL LOCATION AND ID NUMBER	—1228— LINE OF EQUAL GROUNDWATER ELEVATION (FEET MSL), DASHED WHERE INFERRED
RW-1	PRODUCT RECOVERY WELL	
WS-32	WATER SUPPLY WELL	

1

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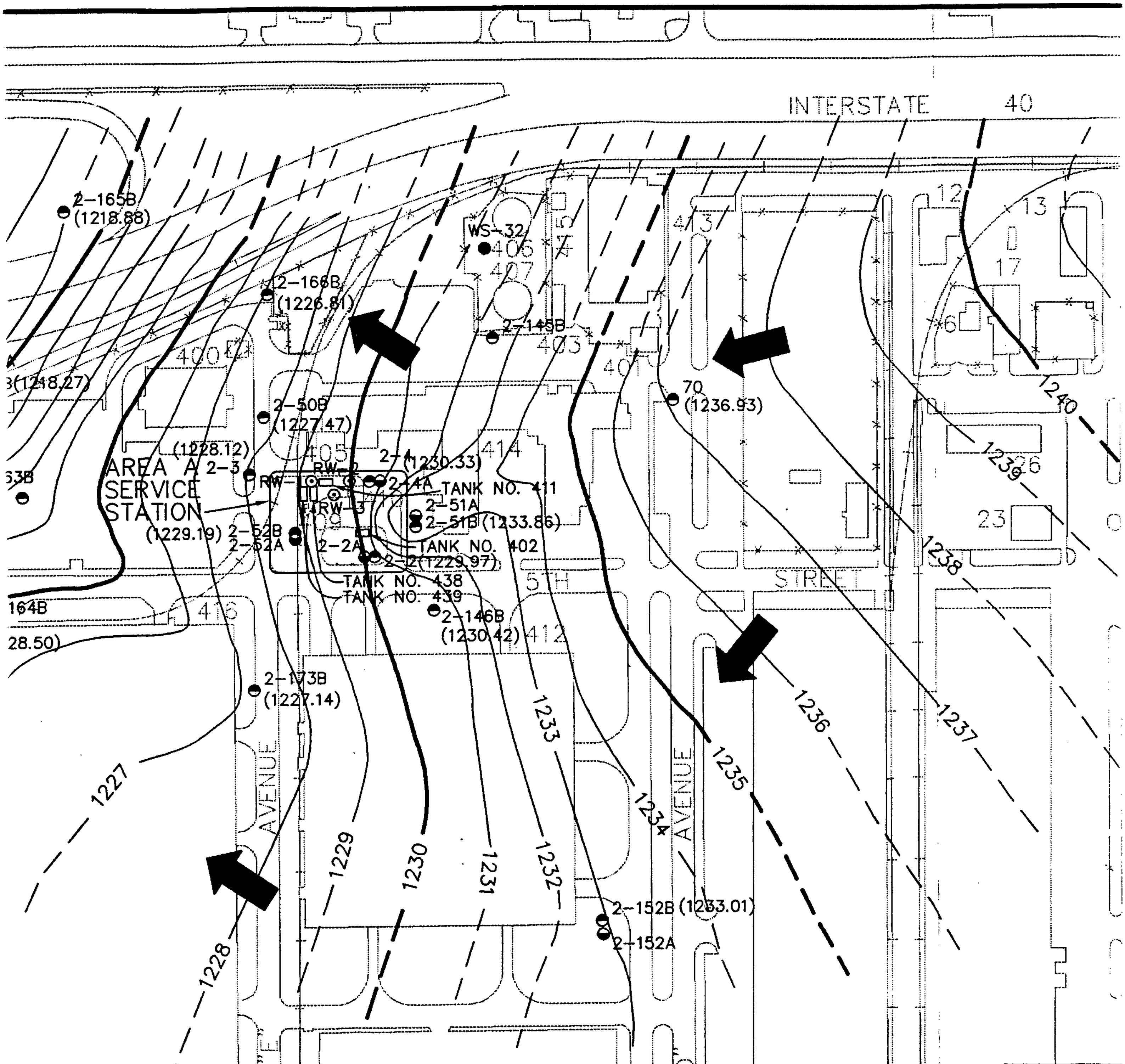

DIRECTION OF GROUNDWATER FLOW

LINE OF EQUAL GROUNDWATER ELEVATION (FEET MSL), DASHED WHERE INFERRED

0 100 200 400

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AREA

Tinker

PARSON
ENGINE

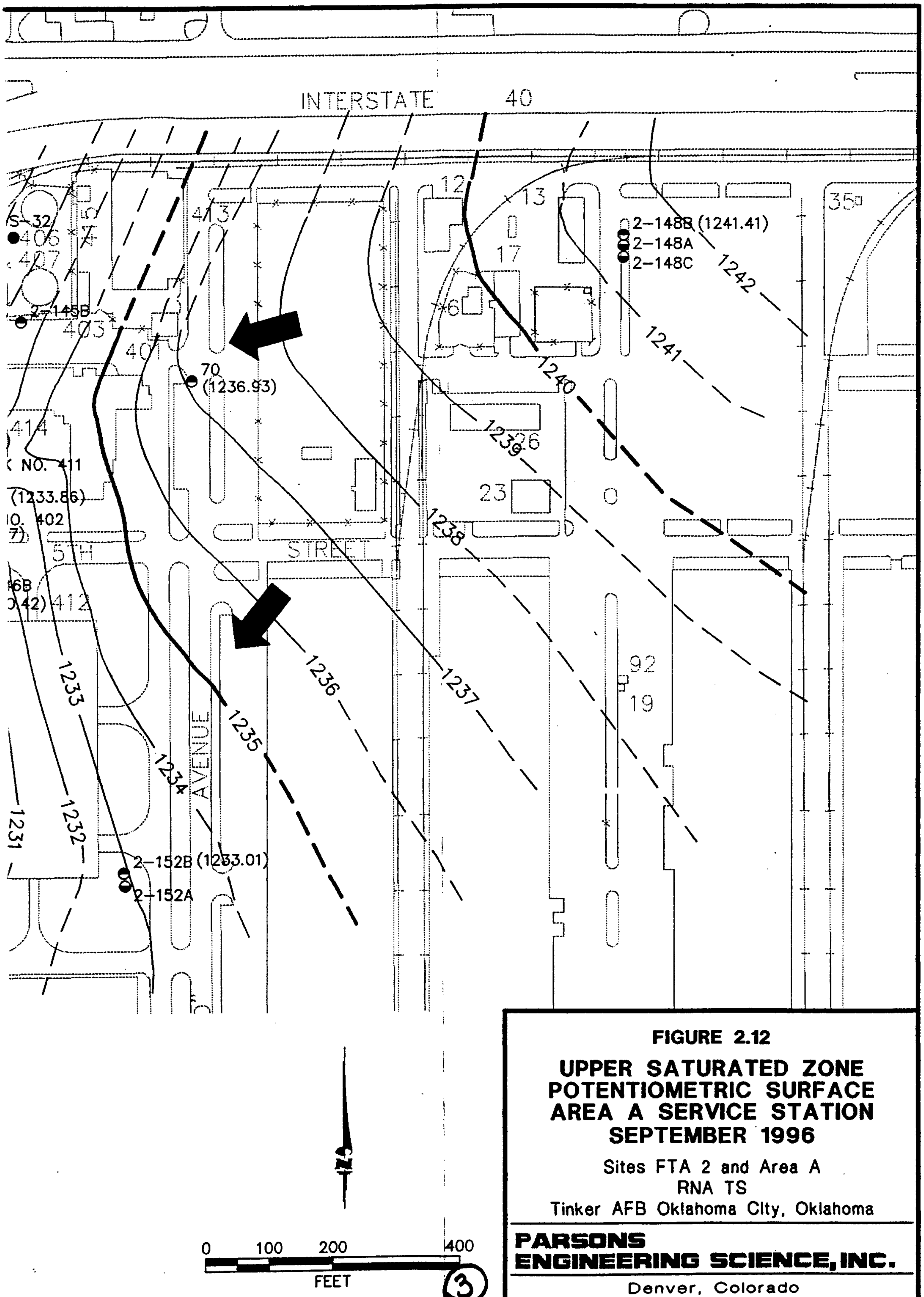

FIGURE 2.12

UPPER SATURATED ZONE POTENTIOMETRIC SURFACE AREA A SERVICE STATION SEPTEMBER 1996

Sites FTA 2 and Area A
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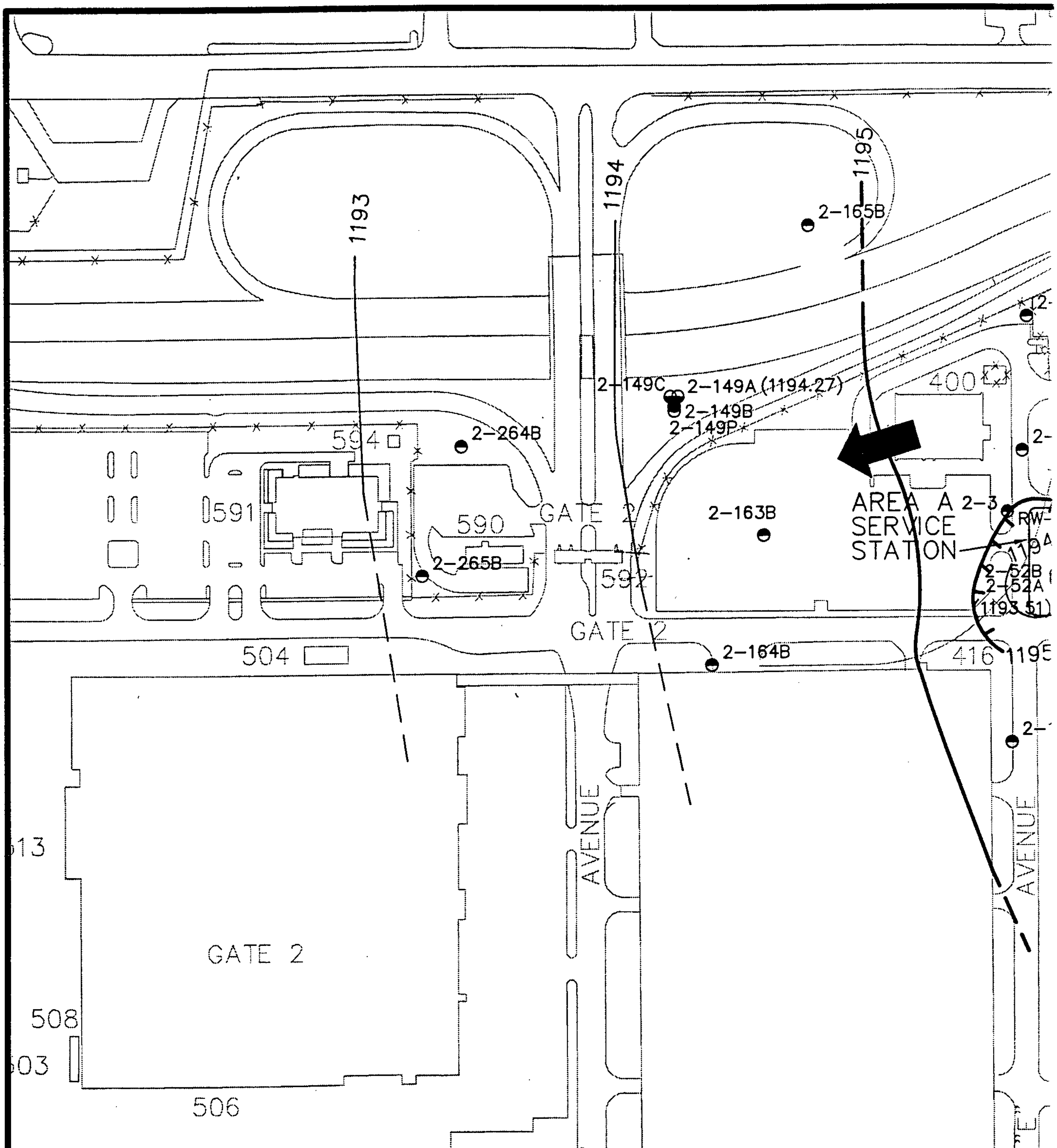

LEGEND

2-165B	UPPER SATURATED ZONE MONITORING WELL LOCATION AND ID NUMBER		DIRECTION OF GROUNDWATER FLC
2-2A	LOWER SATURATED ZONE MONITORING WELL LOCATION AND ID NUMBER	1185	LINE OF EQUAL GROUNDWATER ELEVATION (FEET MSL), DASHED WHERE INFERRED
RW-1	PRODUCT RECOVERY WELL		
WS-32	WATER SUPPLY WELL		

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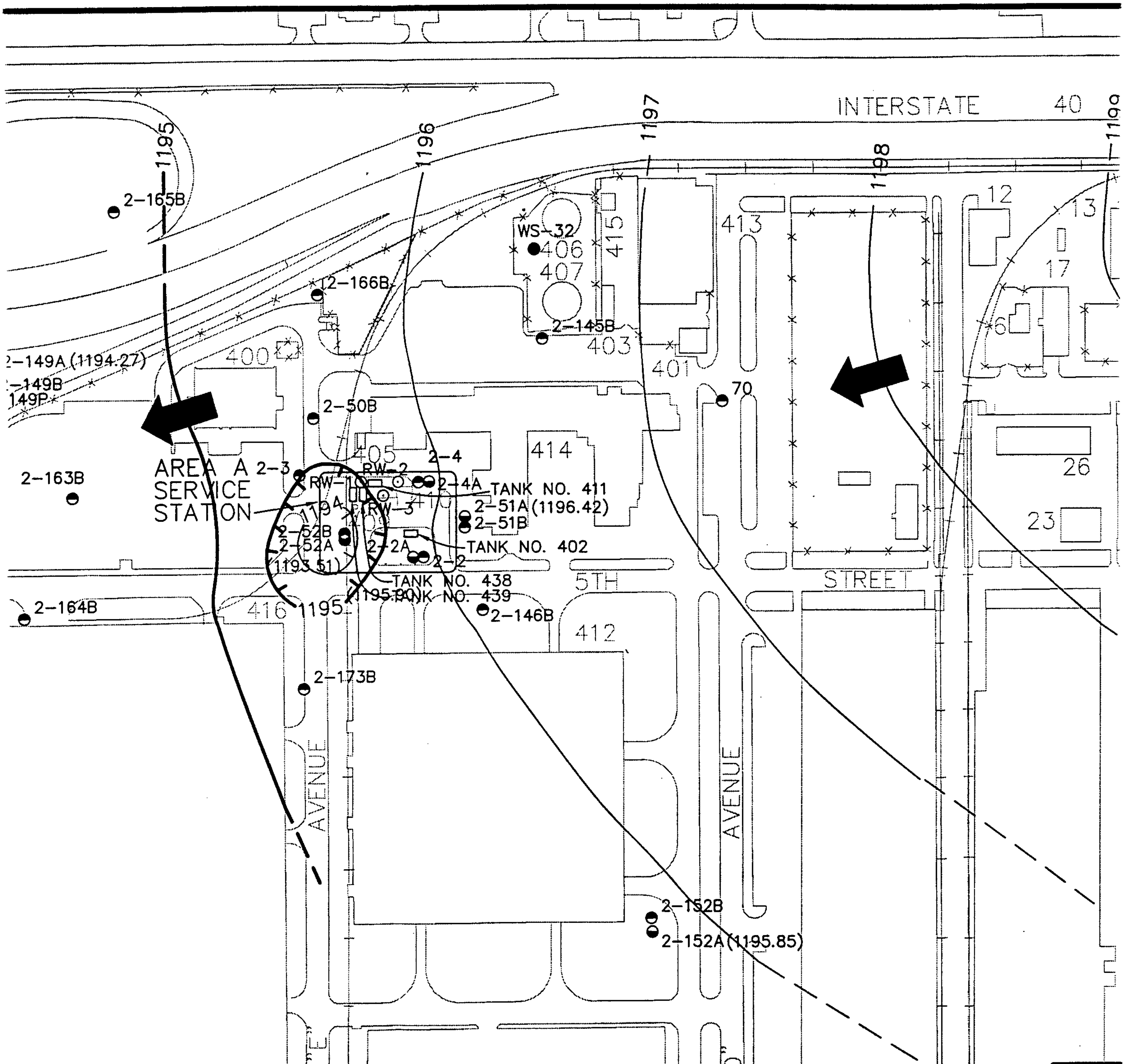
1



DIRECTION OF GROUNDWATER FLOW

1185— LINE OF EQUAL GROUNDWATER ELEVATION (FEET MSL), DASHED WHERE INFERRED

N

0 100 200 400
FEET

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ENG

②

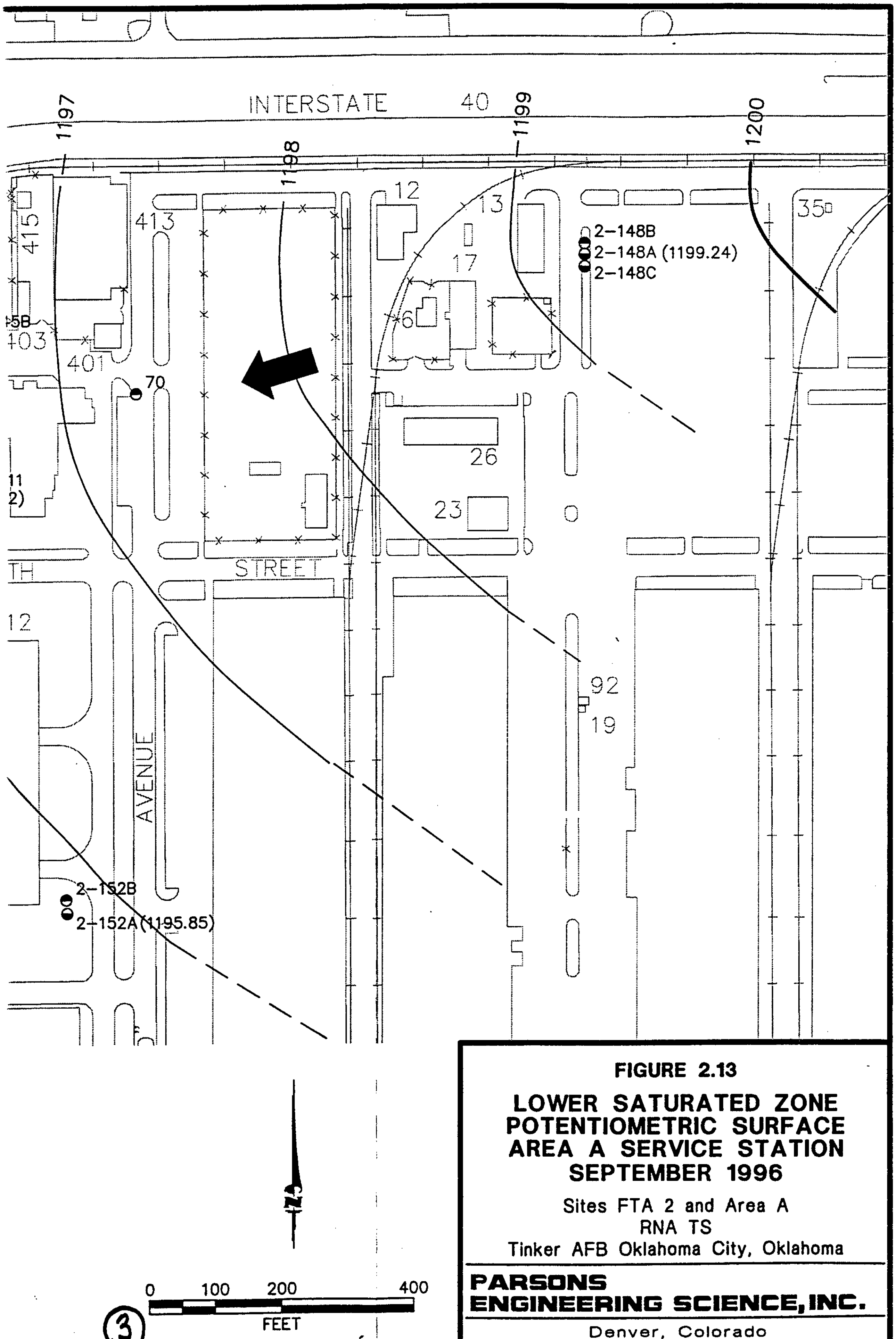

FIGURE 2.13

LOWER SATURATED ZONE POTENTIOMETRIC SURFACE AREA A SERVICE STATION SEPTEMBER 1996

Sites FTA 2 and Area A
RNA TS
Tinker AFB Oklahoma City, Oklahoma

PARSONS ENGINEERING SCIENCE, INC.

Denver, Colorado

2.1.3 Summary of Analytical Results for FTA 2

2.1.3.1 Soil Quality

In a 1987 soil investigation by the USACE (USACE, 1988), seven soil boreholes were drilled to a maximum depth of 7 feet and soil samples were collected and analyzed for VOCs and metals. From October to December 1993, 21 soil samples were collected from 4 locations at depths from 2 to 30 feet bgs and analyzed for VOCs, SVOCs, TPH, and metals (IT, 1994). In 1995, an additional 37 soil samples were collected from 5 soil boreholes and two monitoring well boreholes (TT, 1996). Low concentrations of TPH, VOC, and SVOC compounds were detected, including methylene chloride, 1,1,1-trichloroethane (TCA), butybenzyphthalate, di-n-butylphthalate, and bis(2-ethylhexyl)phthalate. TCA was detected at concentrations ranging from 0.07J (estimated concentration) to 6.7 micrograms per kilogram (μg/kg). Metals detected at the site were within background concentrations. The presence of TCA in the soil suggests the possible use of chlorinated solvents at this site (IT, 1994; TT, 1996). However, the low detected concentrations of TCA do not indicate that Site FTA 2 is a significant source for chlorinated solvents.

2.1.3.2 Groundwater Quality

A total of 14 monitoring wells are present at Site FTA 2 (IT, 1994), with an additional 16 monitoring wells located up- and cross-gradient from the site (Table 2.4). Groundwater samples were collected in December 1993, September to October 1995, and July 1996. Samples were analyzed for VOCs, SVOCs, metals, and general chemistry. A summary of the laboratory analytical results for VOCs in groundwater samples for 1996 is presented in Table 2.4. Summary tables of analytical data for previous sampling events are included in Appendix B. Figure 2.14 is a map of Site FTA 2 depicting monitoring well locations, with reported contamination levels for selected VOCs [tetrachloroethene (PCE), trichloroethene (TCE), *cis*-1,2-dichloroethene

TABLE 2.4
SUMMARY OF VOLATILE ORGANIC COMPOUNDS IN FTA 2 GROUNDWATER
JULY TO SEPTEMBER 1996
SITES FTA 2 AND AREA A
RNA TS
TINKER AFB, OKLAHOMA

Sample Identification	Date Sampled	Units	1,2-Dichlorobenzene	1,3-Dichlorobenzene	1,4-Dichlorobenzene	1,2-Dichloroethane	Chloroform	Chlorobenzene	Methylene Chloride	Tetrachloroethene	Trichloroethene	Trichlorofluoromethane	*cis*-1,2-Dichloroethene	*trans*-1,2-Dichloroethene	Vinyl Chloride
Upper Saturated Zone															
2-62B	7/24/96	(µg/L)[a]	460	9J[b/c]	45[c]	190J	220J	<250	1400B	<250	4300	<250	960	<250	<250
2-63B	7/24/96	(µg/L)	<10	<10	<10	<10	<10	<10	<10	<10	22	91	190	<10	<10
2-64B	7/24/96	(µg/L)	<25	<25	<25	<25	<25	<25	37B[d]	<25	470	<25	180	<25	<25
2-65B	7/24/96	(µg/L)	10	<2	5	4	<2	19	<2	44	55	<2	33	4	2
2-167B	7/24/96	(µg/L)	<1	<1	<1	<1	<1	<1	4B	<1	1	<1	<1	<1	<1
2-168B	7/24/96	(µg/L)	<5	<5	<5	<5	<5	<5	<5	<5	<5	140	19	<5	<5
2-271B	9/11/96	(µg/L)	<0.5	<0.5	<0.5	<0.8	<0.8	<0.5	1JB	<0.8	<0.8	<1	<0.5	<0.8	<1
2-272B	8/22/96	(µg/L)	<0.5	<0.5	<0.5	0.5J	<0.8	<0.5	0.6JB	<0.8	9	<1	0.6	<0.8	<1
2-273B	8/9/96	(µg/L)	<0.5	<0.5	<0.5	<0.8	<0.8	<0.5	0.45JB	<0.8	<0.8	<1	<0.5	<0.8	<1
2-274B	8/22/96	(µg/L)	<0.8	<0.8	<0.8	<0.13	<0.13	<0.8	13JB	<0.13	260	<17	46	<0.13	<17
2-301B	7/16/96	(µg/L)	< 0.5	< 0.5	< 0.5	< 0.8	< 0.8	< 0.5	1JB	< 0.8	< 0.8	< 1	< 0.5	< 0.8	< 1
2-302B	8/30/96	(µg/L)	< 5	< 5	< 5	< 8	< 8	< 5	11JB	12	220	< 10	< 5	< 8	< 10
Lower Saturated Zone															
2-62A	7/24/96	(µg/L)	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
2-63A	7/24/96	(µg/L)	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
2-64A	7/24/96	(µg/L)	<1	<1	<1	<1	<1	<1	1B	<1	<1	0.8J	<1	<1	<1
2-65A	7/24/96	(µg/L)	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1

Tinker AFB, 1996

a/ µg/L indicates micrograms per liter.

b/ J flag indicates an estimated concentration detected below the project reporting limit, but above the method detection limit.

c/ Compound concentration detected in analysis for semi-volatile organic compounds.

d/ B flag indicates compound was detected in the method blank.

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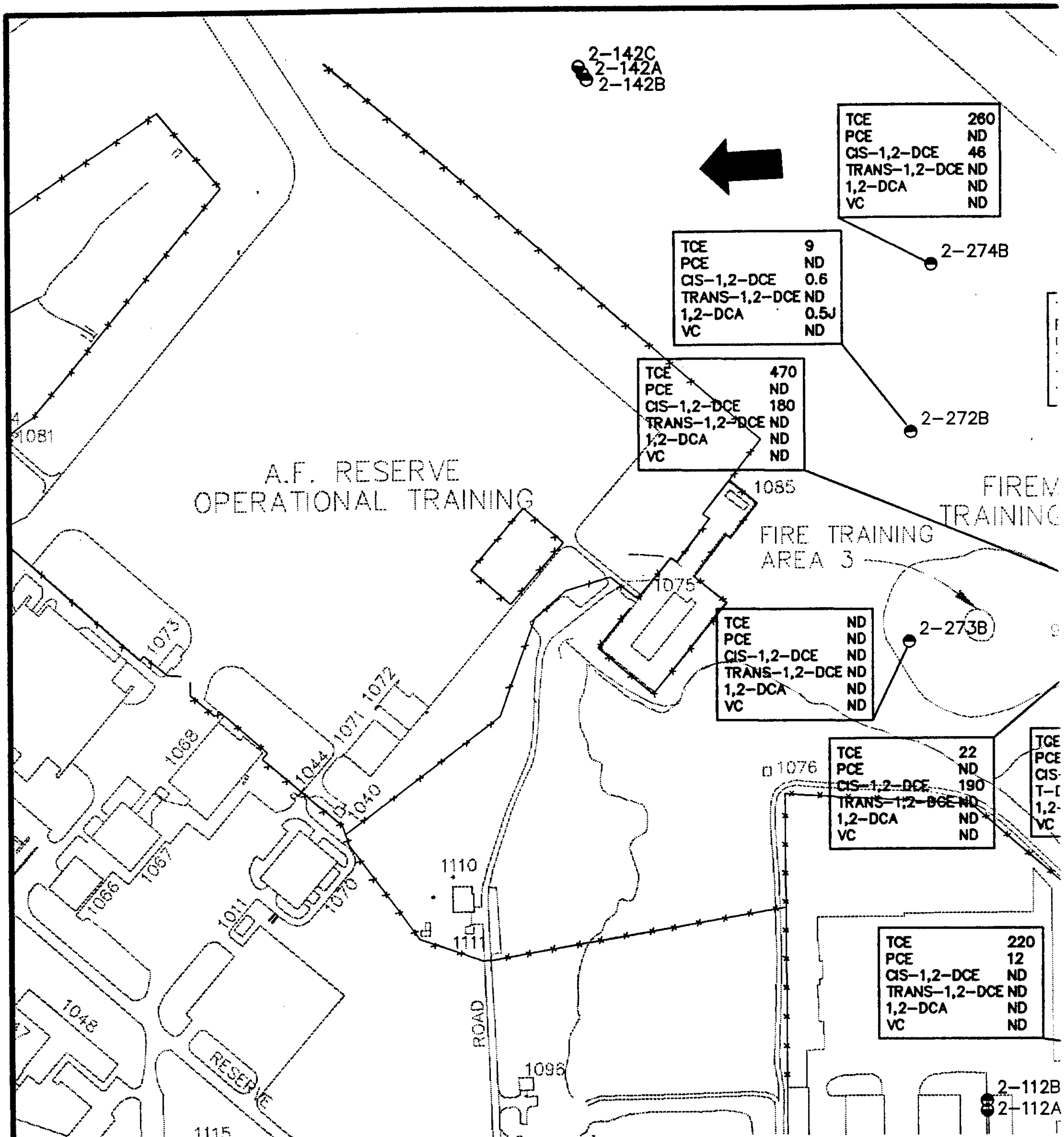

LEGEND

2-142B	UPPER SATURATED ZONE MONITORING WELL LOCATION AND ID NUMBER	TRANS-1,2-DCE	TRANS-1,2-DICHLOROETHE
2-142A	LOWER SATURATED ZONE MONITORING WELL LOCATION AND ID NUMBER	1,2-DCA	1,2-DICHLOROETHANE
TCE	TRICHLOROETHENE	VC	VINYL CHLORIDE
PCE	TETRACHLOROETHENE	ND	NOT DETECTED
CIS-1,2-DCE	CIS-1,2-DICHLOROETHENE		DIRECTION OF GROUNDWA

ALL CONCENTRATIONS IN MICROGRAMS PER L

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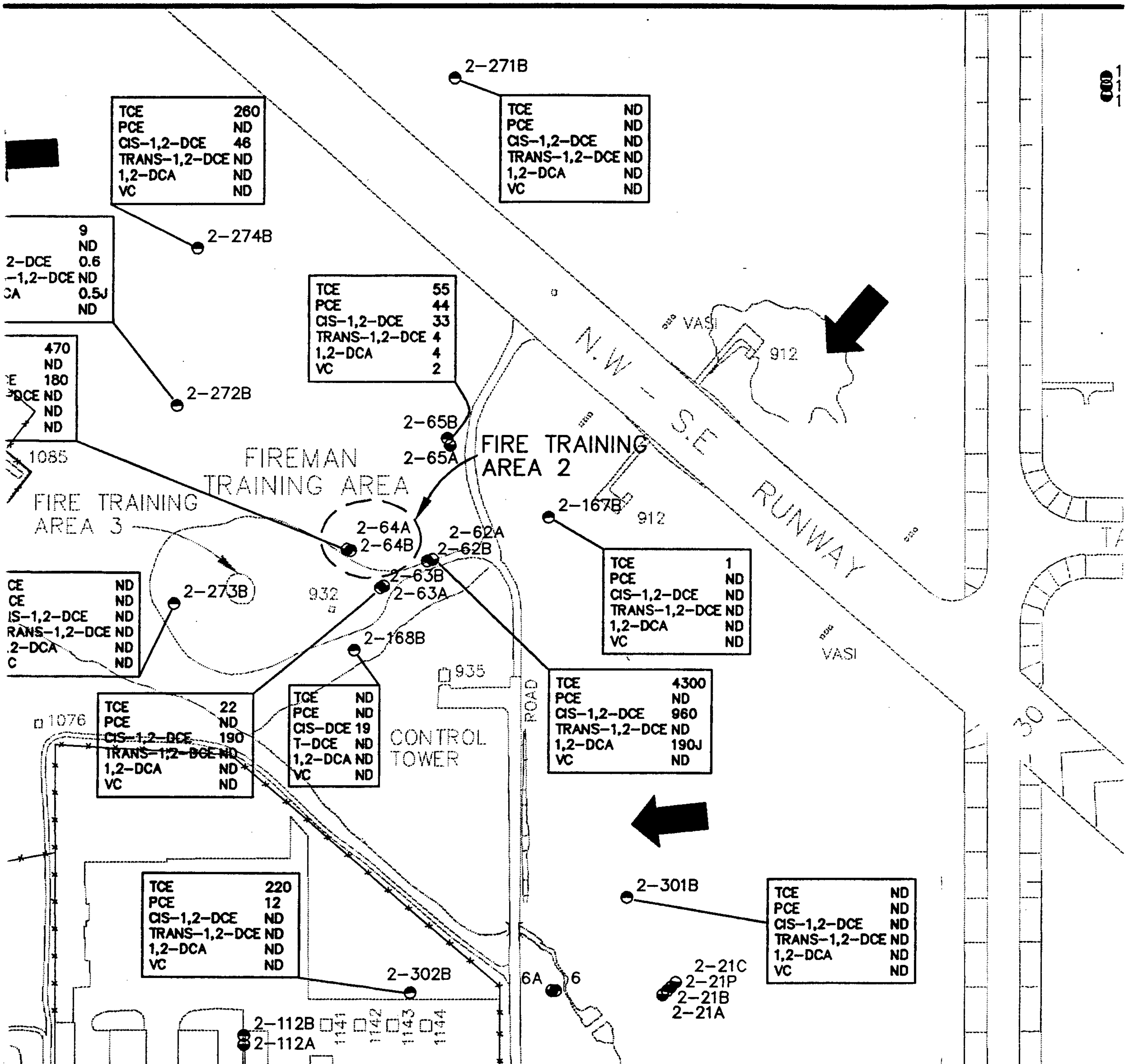


,2-DCE TRANS-1,2-DICHLOROETHENE

1,2-DICHLOROETHANE

VINYL CHLORIDE

NOT DETECTED

DIRECTION OF GROUNDWATER FLOW

CENTRATIONS IN MICROGRAMS PER LITER ($\mu g/L$)

0 150 300 600
FEET

CHL(
HYDR(
IN (
JULY

Si

Tinker /

PARSO
ENGINE

2

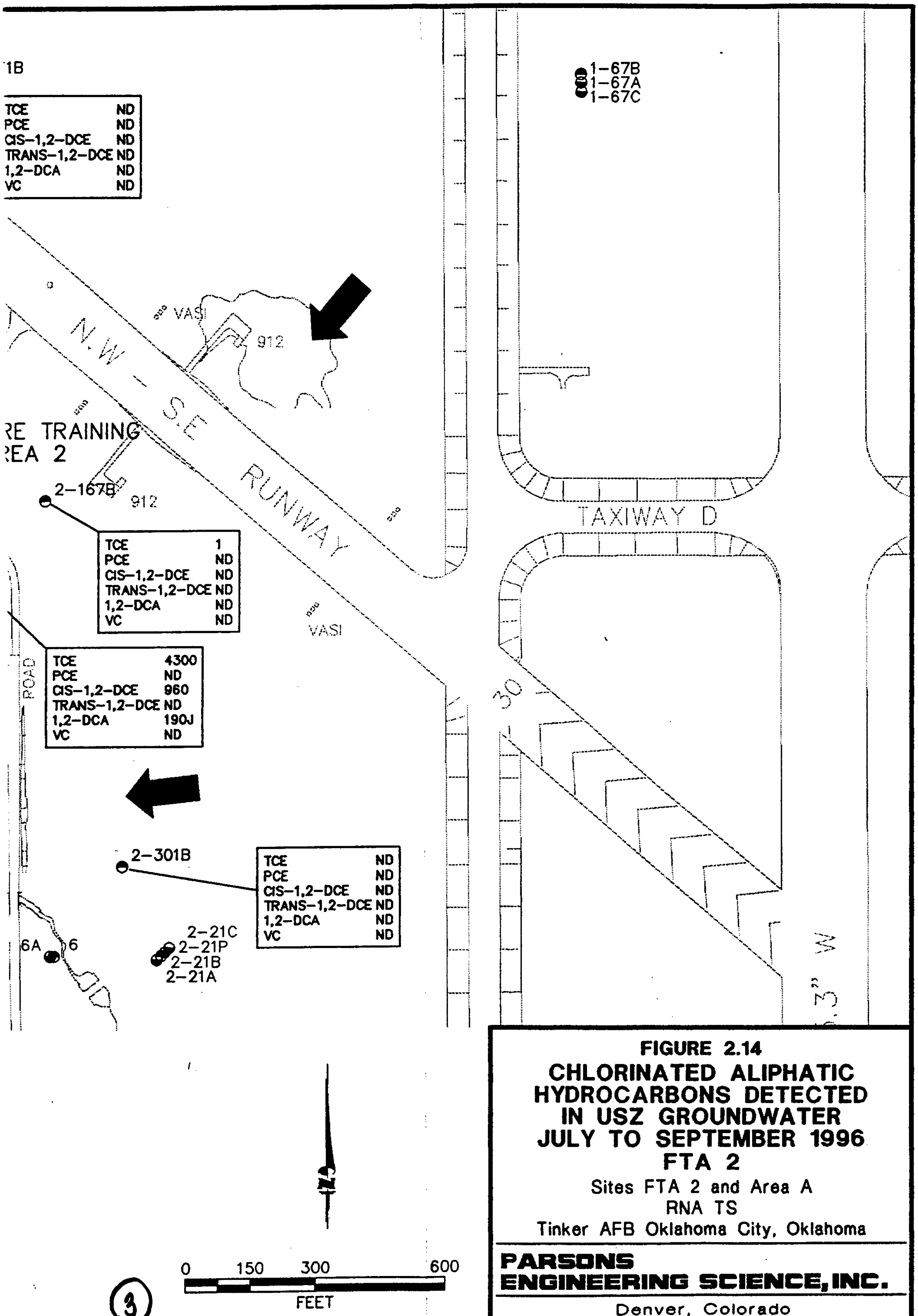


FIGURE 2.14
CHLORINATED ALIPHATIC HYDROCARBONS DETECTED IN USZ GROUNDWATER JULY TO SEPTEMBER 1996 FTA 2

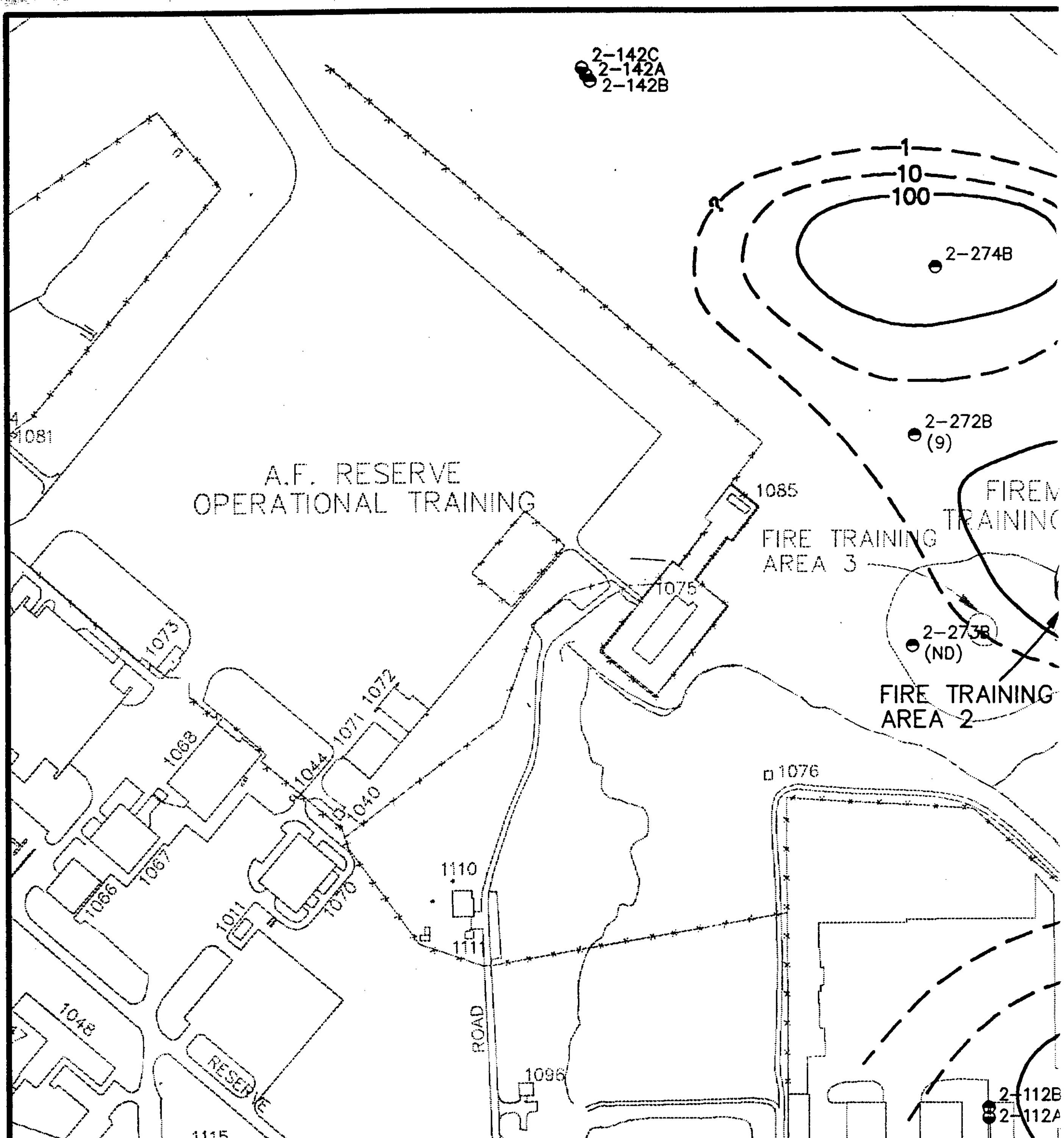
Sites FTA 2 and Area A
RNA TS
Tinker AFB Oklahoma City, Oklahoma

PARSONS ENGINEERING SCIENCE, INC.
Denver, Colorado

(DCE), *trans*-1,2-DCE, 1,2-dichloroethane (DCA), and vinyl chloride (VC)]. Concentration contours for TCE in the USZ for the July 1996 sampling event are depicted in Figure 2.15. No VOC compounds have been detected in the LSZ, indicating that the USZ-LSZ aquitard is an effective barrier to vertical contaminant migration.

TCE was detected at a maximum concentration of 4,300 micrograms per liter (μg/L) at monitoring well 2-62B in July 1996. TCE had previously been detected in concentrations as high as 9,100 μg/L at monitoring well 2-62B in September 1995. The TCE plume at FTA 2 is defined in the USZ by non-detections in wells 2-168B (south), 2-273B (west), 2-271B (north), and to the east by a low detected concentration of 1 μg/L at well 2-167B. However, TCE has also been detected at locations cross-gradient from FTA 2, including well 2-274B (260 μg/L) to the north, and 2-302B (220 μg/L) to the south, indicating that more than one TCE plume may be present in the general fire training area. Other VOC compounds detected at FTA 2 include PCE and breakdown products of PCE and TCE including *cis*-1,2-DCE, *trans*-1,2-DCE, and VC, indicating that natural attenuation of PCE or TCE may be occurring at the site. No BTEX compounds were detected in groundwater samples from the USZ in July 1996.

Only BTEX compounds and organic solvents are included as part of this RNA demonstration; therefore, results for other potential contaminants such as herbicides, polynuclear aromatic hydrocarbons (PAHs), polychlorinated biphenyls (PCBs), pesticides, or metals are not summarized in this work plan. These compounds have been addressed in previous reports. For information on these compounds the reader is referred to IT, 1994.



LEGEND

2-142B (4300) — UPPER SATURATED ZONE MONITORING WELL LOCATION AND ID NUMBER [CONCENTRATION OF TCE IN MICROGRAMS PER LITER (μg/L)]

2-142A — LOWER SATURATED ZONE MONITORING WELL LOCATION AND ID NUMBER

ND — NOT DETECTED

DIRECTION OF GROUNDWATER FLOW

—60— LINE OF EQUAL TCE CONCENTRATION (μg/L), DASHED WHERE INFERRED

1

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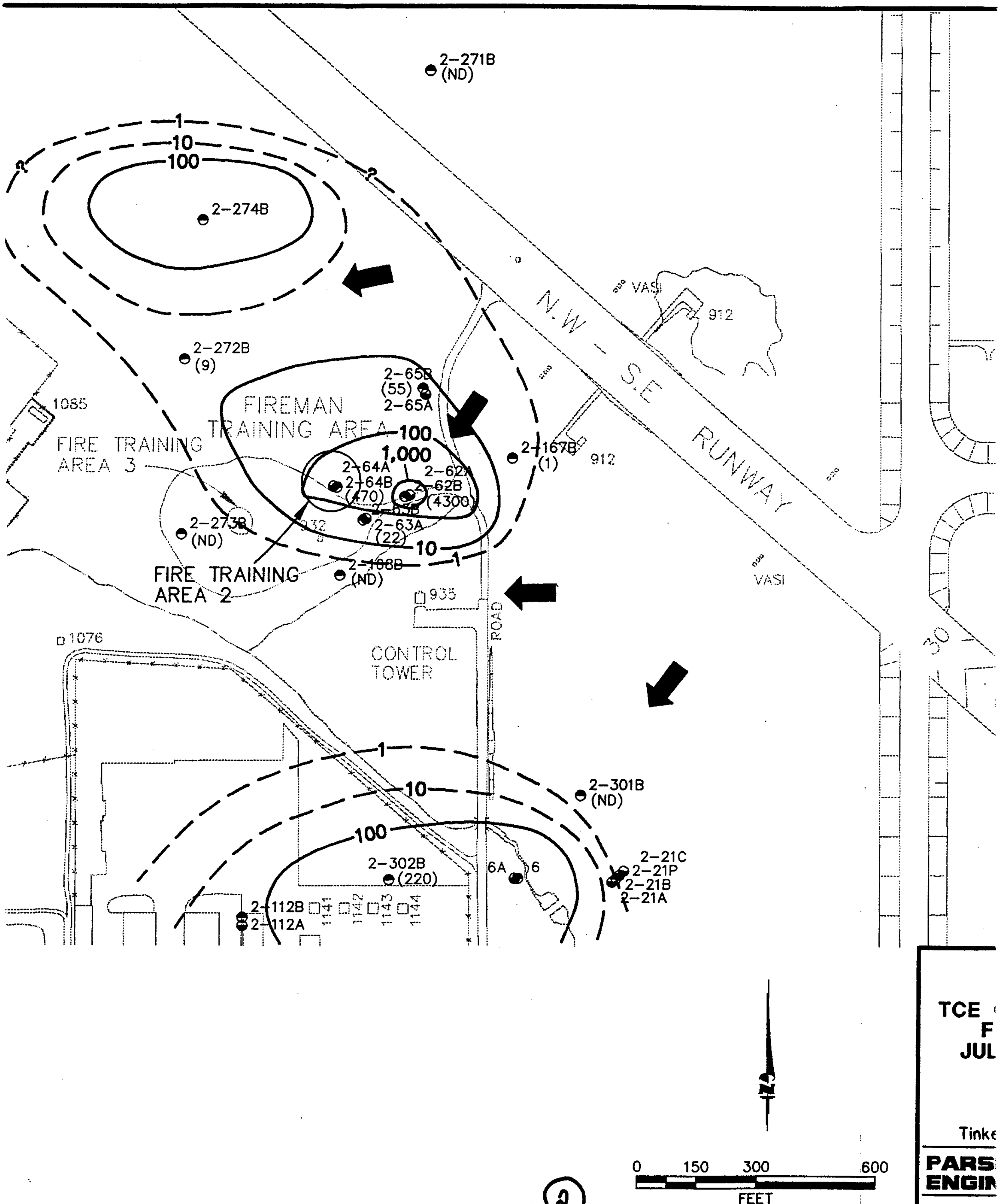

2-271B
(ND)
1
10
100
2-274B
N.W. - S.E. RUNWAY
VASI
912
2-272B
(9)
2-65B
(55)
2-65A
FIREMAN
TRAINING AREA
1085
FIRE TRAINING
AREA 3
1,000
2-64A
2-64B
(470)
2-62A
2-62B
(4300)
2-63A
(22)
2-167B
(1)
2-273B
(ND)
FIRE TRAINING
AREA 2
2-168B
(ND)
935
ROAD
1076
CONTROL
TOWER
30
2-301B
(ND)
2-302B
(220)
6A
6
2-21C
2-21P
2-21B
2-21A
2-112B
2-112A
1141
1142
1143
1144
TCE
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JUL
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PARS
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0
150
300
600
FEET

(2)

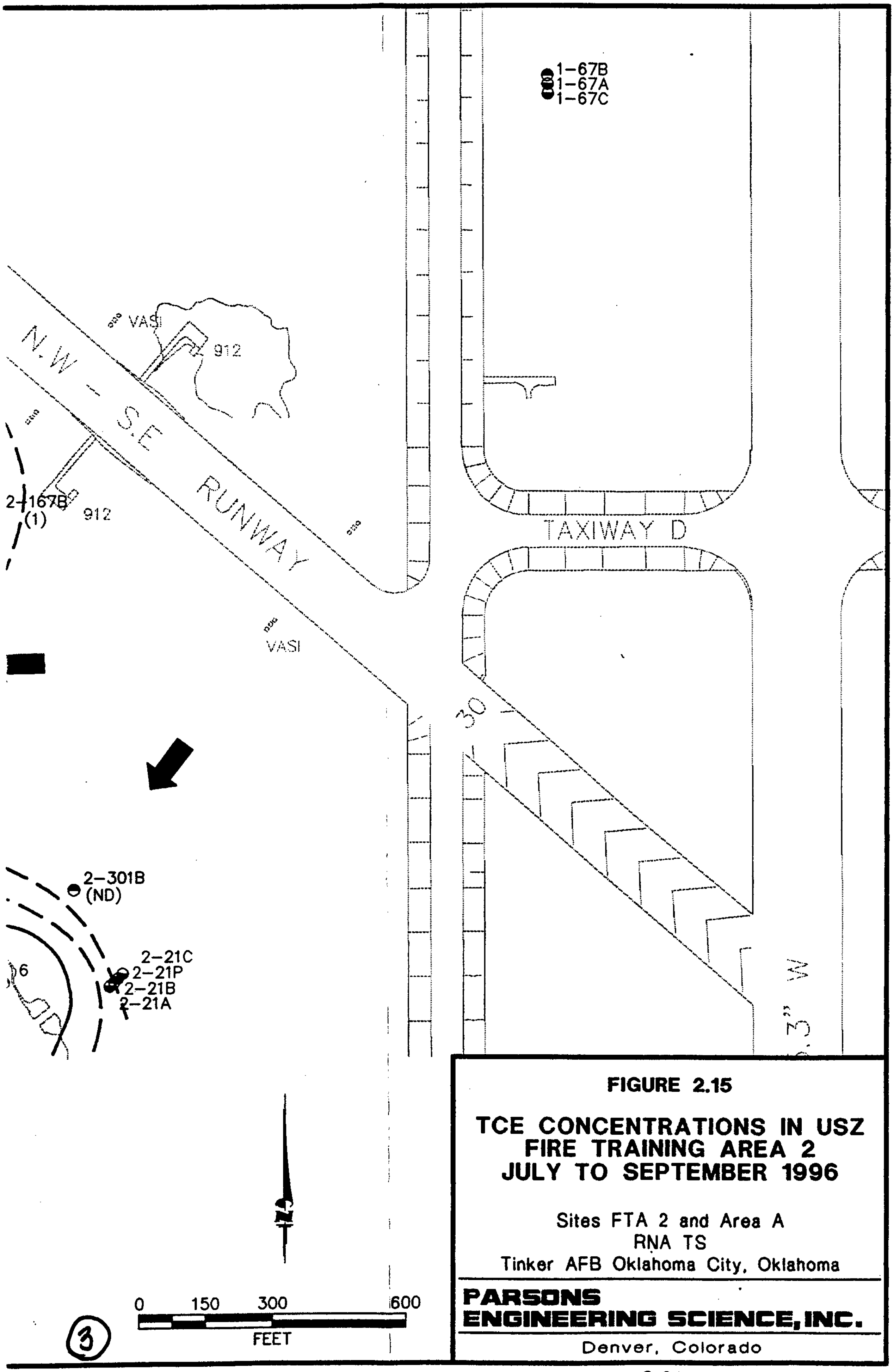


FIGURE 2.15

TCE CONCENTRATIONS IN USZ
FIRE TRAINING AREA 2
JULY TO SEPTEMBER 1996

Sites FTA 2 and Area A
RNA TS
Tinker AFB Oklahoma City, Oklahoma

PARSONS
ENGINEERING SCIENCE, INC.

Denver, Colorado

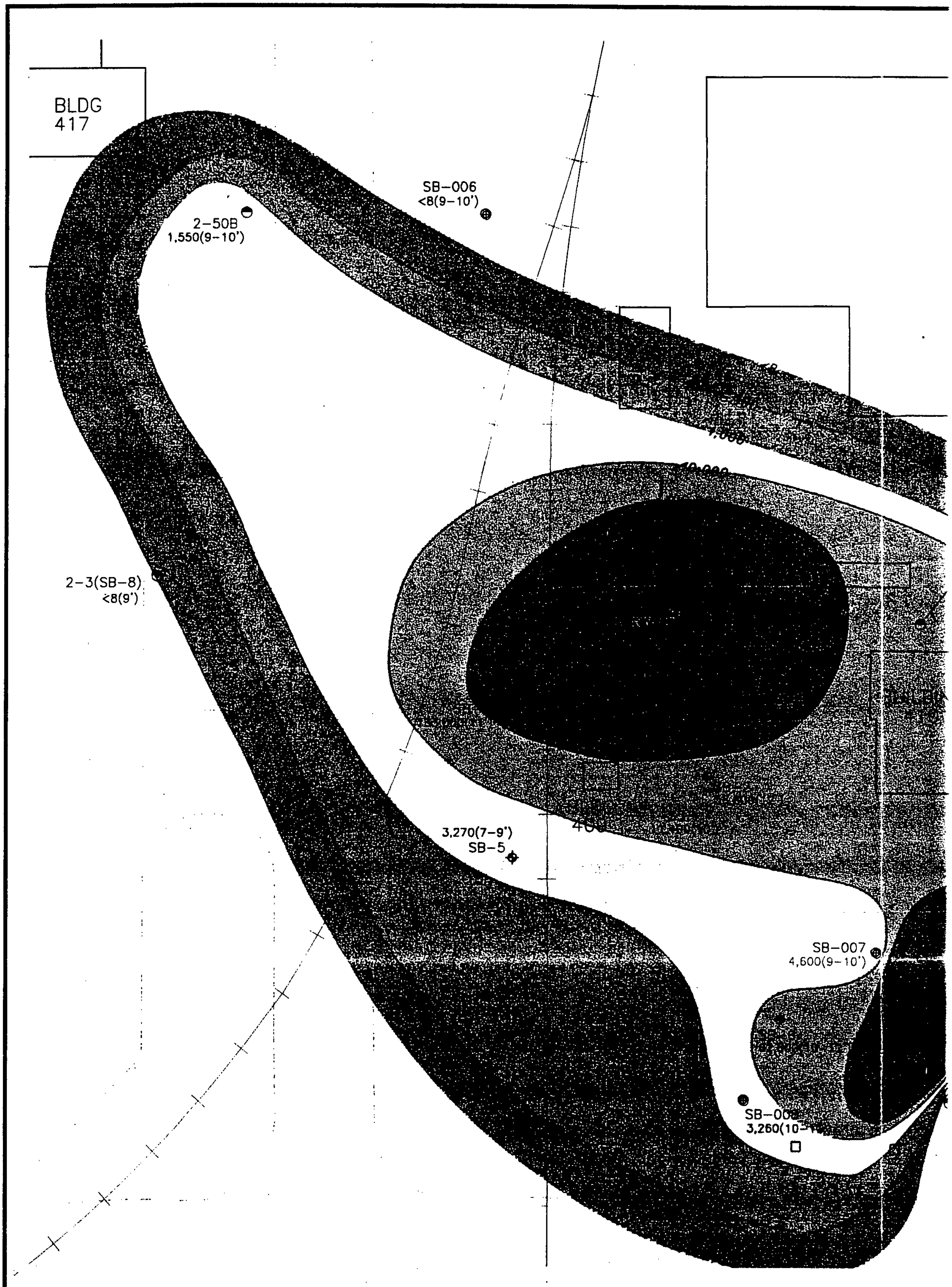
2.1.4 Summary of Analytical Results for Site Area A

2.1.4.1 Soil Quality

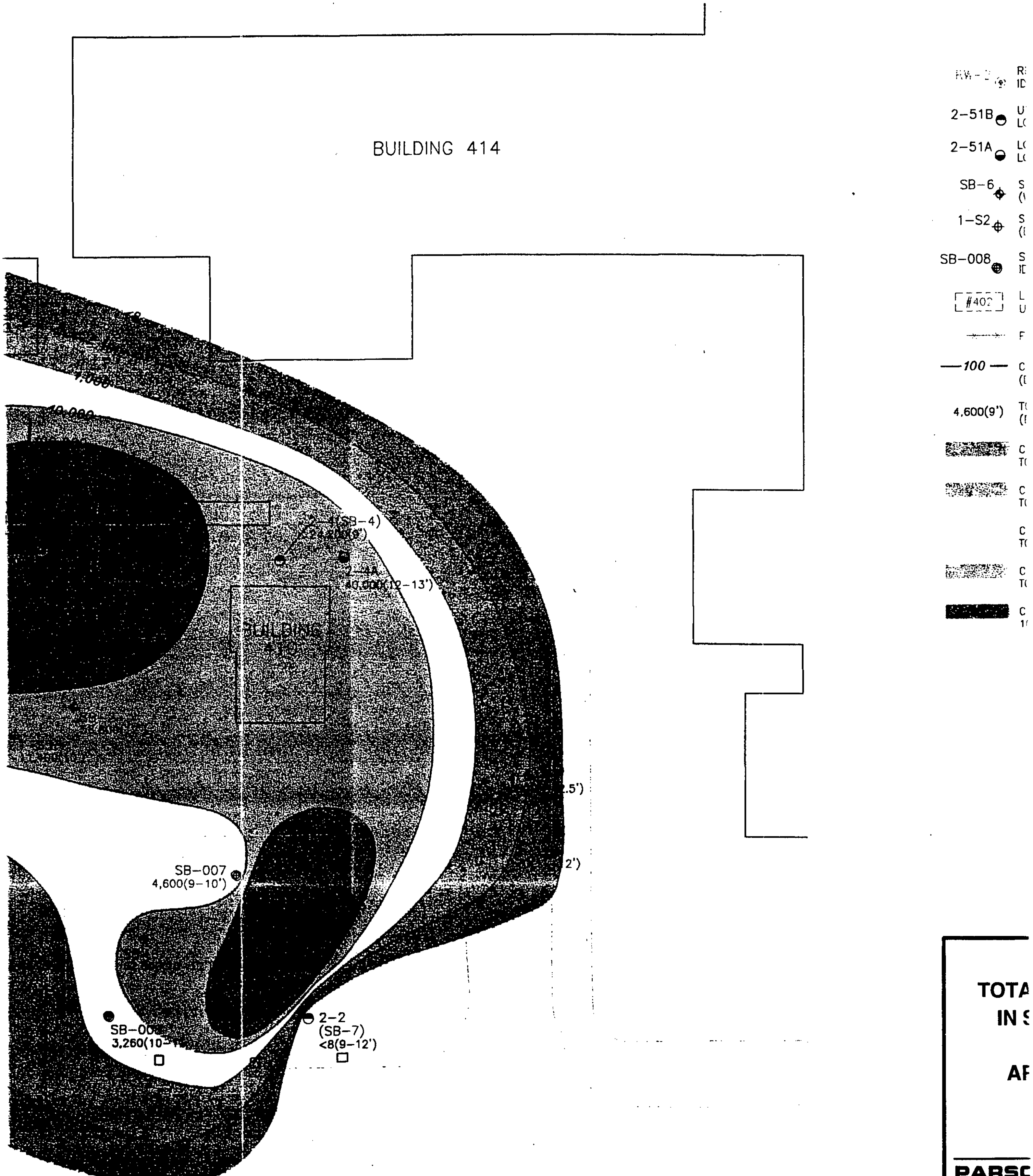
Soil samples collected and analyzed from Site Area A include 11 samples from five soil boreholes drilled in 1990 by ERI and 50 samples from eight soil boreholes drilled by WSCI in 1991. These samples were analyzed for BTEX, TPH, and total lead. An additional 35 samples from ten soil boreholes were collected by IT from October 1993 to January 1994, and analyzed for VOCs (including BTEX), SVOCs, and metals. All soil samples were collected from the USZ stratigraphic interval. Analytical summary tables for soil sampling results at Area A are included in Appendix C.

Analytical results indicate that the highest concentrations of BTEX were encountered in soil samples from boreholes located within 20 to 40 feet of existing USTs. Mobile light non-aqueous phase liquid (LNAPL) was also detected at the Area A service station. The proximity to existing USTs suggests that residual soil BTEX contamination and mobile LNAPL originated from leaking USTs at Area A. Figure 2.16 shows soil borehole locations and the distribution of total BTEX in soil at the Area A Service Station.

Only low concentrations of other VOC compounds, including 1,2-DCA, 2-butanone, acetone, chlorobenzene, methylene chloride, TCE, and *cis*-1,2-DCE, have been detected in Area A soil samples. Chlorinated solvents (TCE and *cis*-1,2-DCE) were only detected in a single soil sample at a depth of 20 to 21 feet bgs in soil borehole SB-006, located to the north of the area of soil impacted by BTEX contamination. This CAH detection is may not be sufficient to account for the concentrations of dissolved CAH compounds present in Area A groundwater, as discussed in the following section. To date a CAH source has not been identified at Area A.



Source: IT, 1996.



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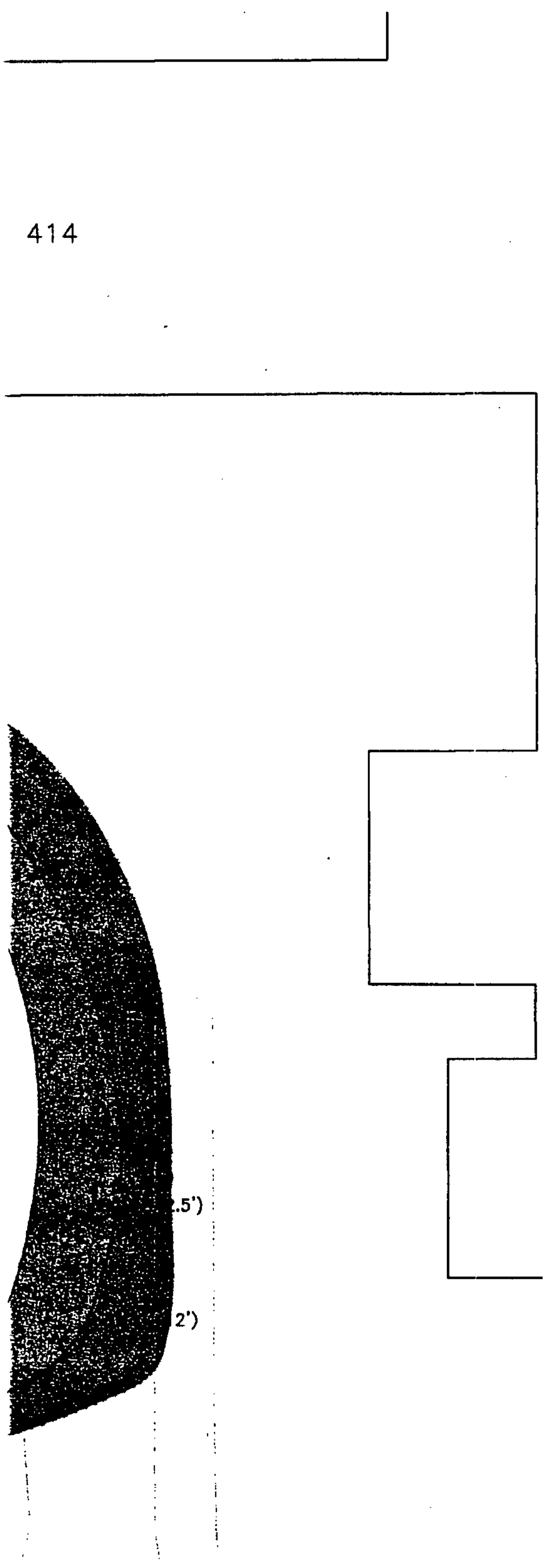

LEGEND

RW-2 — RECOVERY WELL LOCATION AND ID NUMBER (WSCI, 1992)

2-51B — UPPER SATURATED ZONE MONITORING WELL LOCATION AND ID NUMBER

2-51A — LOWER SATURATED ZONE MONITORING WELL LOCATION AND ID NUMBER

SB-6 — SOIL BORING LOCATION AND ID NUMBER (WSCI, 1992)

1-S2 — SOIL BORING LOCATION AND ID NUMBER (ERI, 1990)

SB-008 — SOIL BORING LOCATION AND ID NUMBER (IT, 1994)

#407 — LOCATION OF INACTIVE/CLOSED UNDERGROUND STORAGE TANK

FENCE

—100— CONTOUR INTERVAL (DASHED WHERE INFERRED)

4,600(9') TOTAL BTEX CONCENTRATION (DEPTH OF SOIL BELOW GROUND SURFACE)

CONCENTRATIONS FROM <8 TO 100µg/kg

CONCENTRATIONS FROM 100 TO 1000µg/kg

CONCENTRATIONS FROM 1000 TO 10,000µg/kg

CONCENTRATIONS FROM 10,000 TO 100,000µg/kg

CONCENTRATIONS OVER 100,000µg/kg

N

0 30
FEET

FIGURE 2.16

TOTAL BTEX CONCENTRATIONS IN SOIL AT APPROXIMATELY 10 FEET BGS AREA A SERVICE STATION

Sites FTA 2 and Area A
RNA TS
Tinker AFB, Oklahoma

PARSONS ENGINEERING SCIENCE, INC.
Denver, Colorado

2.1.4.2 Groundwater Quality

Groundwater samples have been collected during sampling events in January 1994, January 1995, October 1995, and August 1996 (IT, 1996; and Tinker AFB, 1996). Groundwater samples were analyzed for BTEX, VOCs, SVOCs, metals, and general chemistry. In addition, a temporary well sampling event was conducted from April to May, 1995 (IT, 1995c). Analytical results for VOCs for 1996 sampling are summarized in Table 2.5. Summary tables for previous sampling events are included in Appendix C.

BTEX compounds were detected in the USZ, but not in any samples collected from the LSZ. The highest concentrations of BTEX compounds detected in the USZ for August 1996 were from monitoring well 2-50B, with the sample containing 12,000 μg/L of benzene, 2,200 μg/L of ethylbenzene, 17,000 μg/L of toluene, and 9,300 μg/L of total xylenes. Well 2-50B is located at the northeastern fringe of the product plume. The BTEX plume extends towards the west and northwest, in the primary direction of USZ groundwater flow. Concentrations for total BTEX and the extent of free product from the January and April-May 1995 groundwater sampling events are shown on Figure 2.17.

Chlorinated solvents have been detected in both the USZ and the LSZ. In the USZ, maximum chlorinated solvent concentrations detected in August and September 1996 include 86 μg/L for TCE, 1,100 μg/L for *cis*-1,2-DCE, and 40 μg/L for 1,2-DCA. Other chlorinated solvents detected in earlier sampling events include low concentrations of PCE and VC. Figure 2.18 shows concentrations of CAHs detected in USZ and LSZ monitoring wells sampled in August and September 1996. High reporting limits for groundwater samples collected within the BTEX plume may hinder detection of lower concentrations of chlorinated solvents within the BTEX plume.

TABLE 2.5
SUMMARY OF VOLATILE ORGANIC COMPOUNDS IN AREA A GROUNDWATER
AUGUST TO SEPTEMBER 1996
SITES FTA 2 AND AREA A
RNA TS
TINKER AFB, OKLAHOMA

Sample Identification	Date Sampled	Units	1,2,4-Trimethylbenzene	1,2-Dichlorobenzene	1,2-Dichloroethane	1,3,5-Trimethylbenzene	Benzene	Carbon Tetrachloride	Chloroform	cis-1,2-Dichloroethene	Ethylbenzene	Isopropylbenzene	Methylene Chloride	Naphthalene	n-Propylbenzene	Toluene	Trichloroethene	Xylenes (Total)
Upper Saturated Zone																		
2-2	8/16/96	(µg/L)[a]	<12	< 12	<12	<12	400	<12	<12	<12	<12	10J[b]	<12	16	19	<12	<12	<12
2-3	8/14/96	(µg/L)	<2	<2	<2	<2	110	<2	<2	75	210	36	10	86	43	25	86	89
2-4	8/16/96	(µg/L)	2500	<500	<500	820	9800	<500	<500	<500	1700	410J	<500	940	<500	14000	<500	9100
2-50B	8/14/96	(µg/L)	1700	< 500	<500	470J	12000	<500	<500	1100	2200	<500	<500	980	1300	17000	<500	9300
2-51B	8/14/96	(µg/L)	9	< 5	<5	<5	81	<5	<5	<5	8	<5	<5	24	<5	<5	<5	15
2-52B	8/15/96	(µg/L)	<1	<1	<1	<1	<1	<1	2	<1	<1	<1	0.9J	2	<1	<1	8	<1
2-163B	8/14/96	(µg/L)	<1	<1	40	<1	<1	<1	<1	<1	<1	<1	4	<1	<1	<1	<1	<1
2-164B	8/14/96	(µg/L)	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	3	<1	<1	<1	<1	<1
2-165B	8/14/96	(µg/L)	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	2	<1	<1	<1	<1	<1
2-166B	8/14/96	(µg/L)	<1	1	<1	<1	<1	<1	0.9J	<1	<1	<1	2	<1	<1	<1	10	0.9J
2-264B	9/12/96	(µg/L)	< 0.5	< 0.5	< 0.8	< 0.5	< 0.8	< 1	< 0.8	< 0.5	< 0.5	< 0.8	1JB[c]	< 0.8	< 0.8	< 0.8	< 0.8	< 0.5
2-265B	9/12/96	(µg/L)	< 0.5	< 0.5	< 0.8	< 0.5	< 0.8	< 1	0.4J	< 0.5	< 0.5	< 0.8	2JB	< 0.8	< 0.8	< 0.8	< 0.8	< 0.5
2-146B	8/14/96	(µg/L)	<1	< 1	<1	<1	<1	<1	<1	<1	<1	<1	2	<1	<1	<1	0.8J	<1
Lower Saturated Zone																		
2-2A	8/16/96	(µg/L)	<5	<10	<5	<5	<5	38	4J	<5	<5	<5	<5	<5	<5	<5	120	<5
2-4A	8/15/96	(µg/L)	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	45	<2

Tinker AFB, 1996

a/ µg/L indicates micrograms per liter.

b/ J flag indicates an estimated concentration detected below the project reporting limit, but above the method detection limit.

c/ B flag indicates compound was detected in the method blank.

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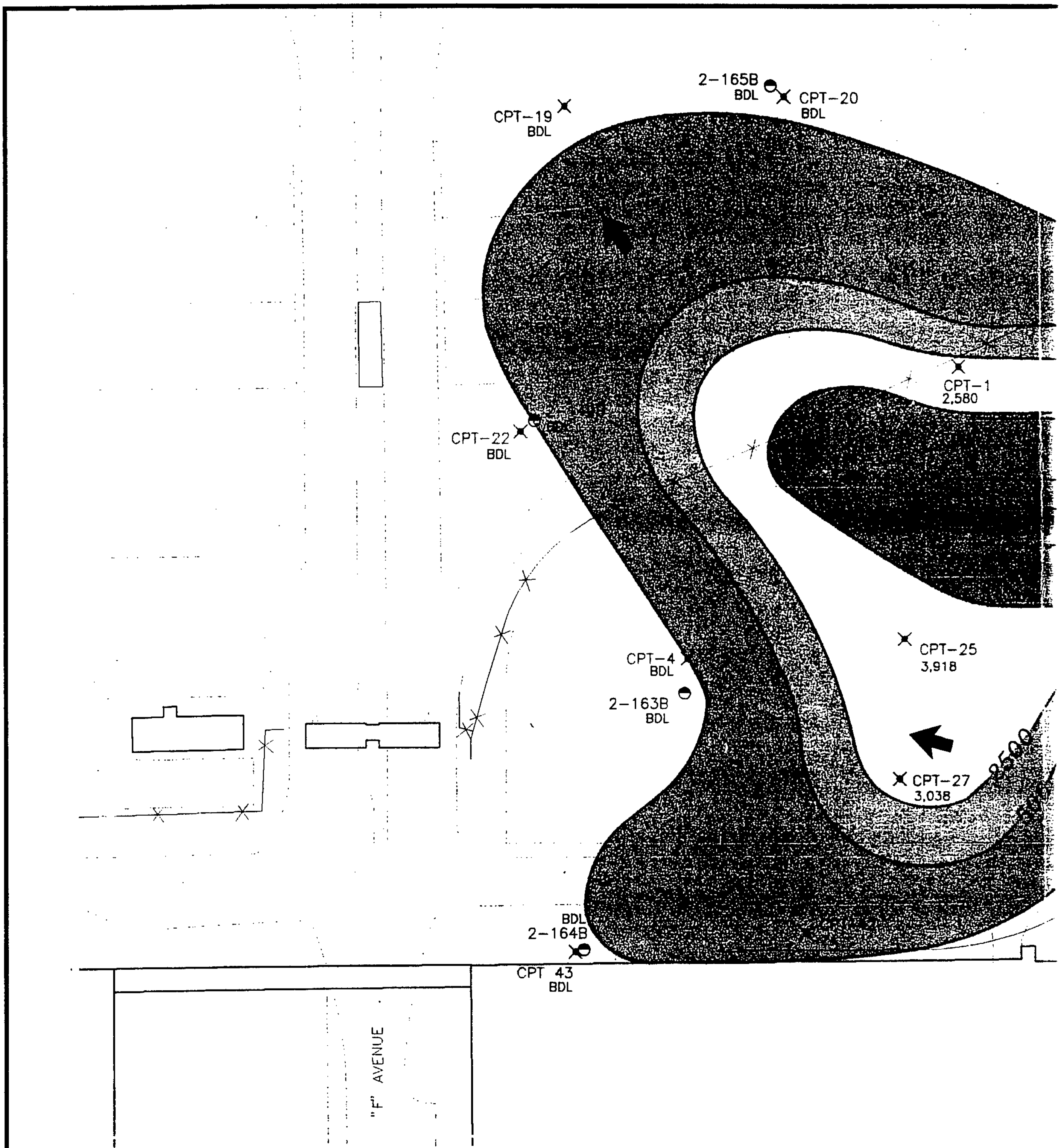


LEGEND

CONCENTRATIONS FROM BDL TO 500 $\mu g/L$

CONCENTRATIONS FROM 500 TO 2500 $\mu g/L$

CONCENTRATIONS FROM 2500 TO 5000 $\mu g/L$

CONCENTRATIONS OVER 5000 $\mu g/L$

—500— LINES OF EQUAL BTEX CONCENTRATION ($\mu g/L$)

AREA OF IDENTIFIED LIGHT NON-AQUEOUS PHASE LIQUID

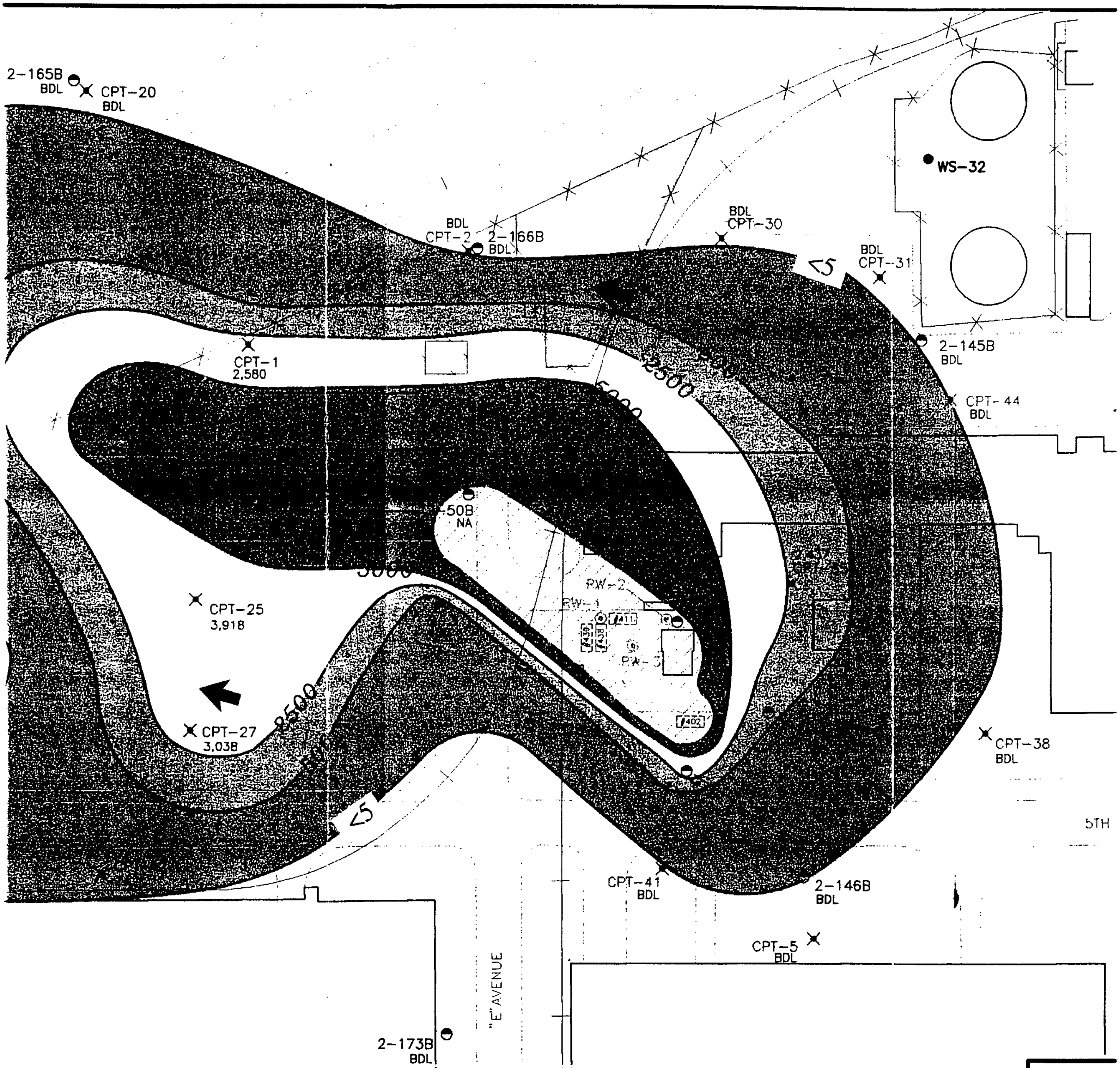
RW-2 EXISTING RECOVERY WELL LOCATION AND ID NUMBER (WSCI, 1992)

CPT-44 3,918 TEMPORARY GROUNDWATER PROBE SAMPLE LOCATION AND ID NUMBER AND TOTAL BTEX CONCENTRATION ($\mu g/L$)

2-51B 535 UPPER SATURATED ZONE MONITORING WELL LOCATION AND ID NUMBER AND JANUARY 1995 TOTAL BTEX CONCENTRATION ($\mu g/L$)

DIRECTION OF GROUNDWATER FLOW

Source: IT, 1996.



- 2 EXISTING RECOVERY WELL LOCATION AND ID NUMBER (WSCI, 1992)

-44 918 TEMPORARY GROUNDWATER PROBE SAMPLE LOCATION AND ID NUMBER AND TOTAL BTEX CONCENTRATION (µg/L)

51B 535 UPPER SATURATED ZONE MONITORING WELL LOCATION AND ID NUMBER AND JANUARY 1995 TOTAL BTEX CONCENTRATION (µg/L)

DIRECTION OF GROUNDWATER FLOW

WS-32 WATER SUPPLY WELL

LOCATION OF INACTIVE/CLOSED UNDERGROUND STORAGE TANK

FENCE

BDL BELOW REPORTED DETECTION LIMITS

NA NOT ANALYZED

TOT/
IN I
AI

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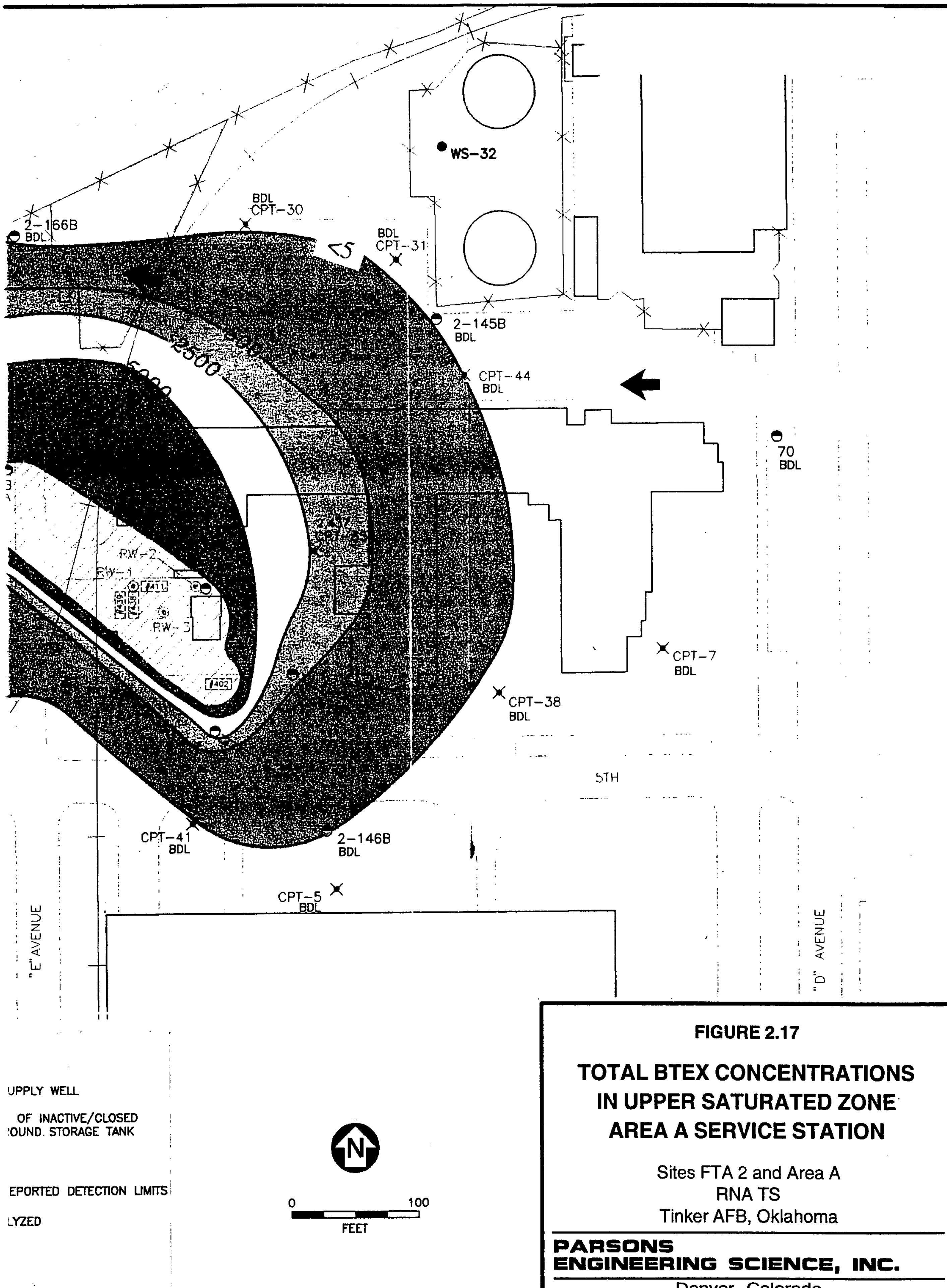


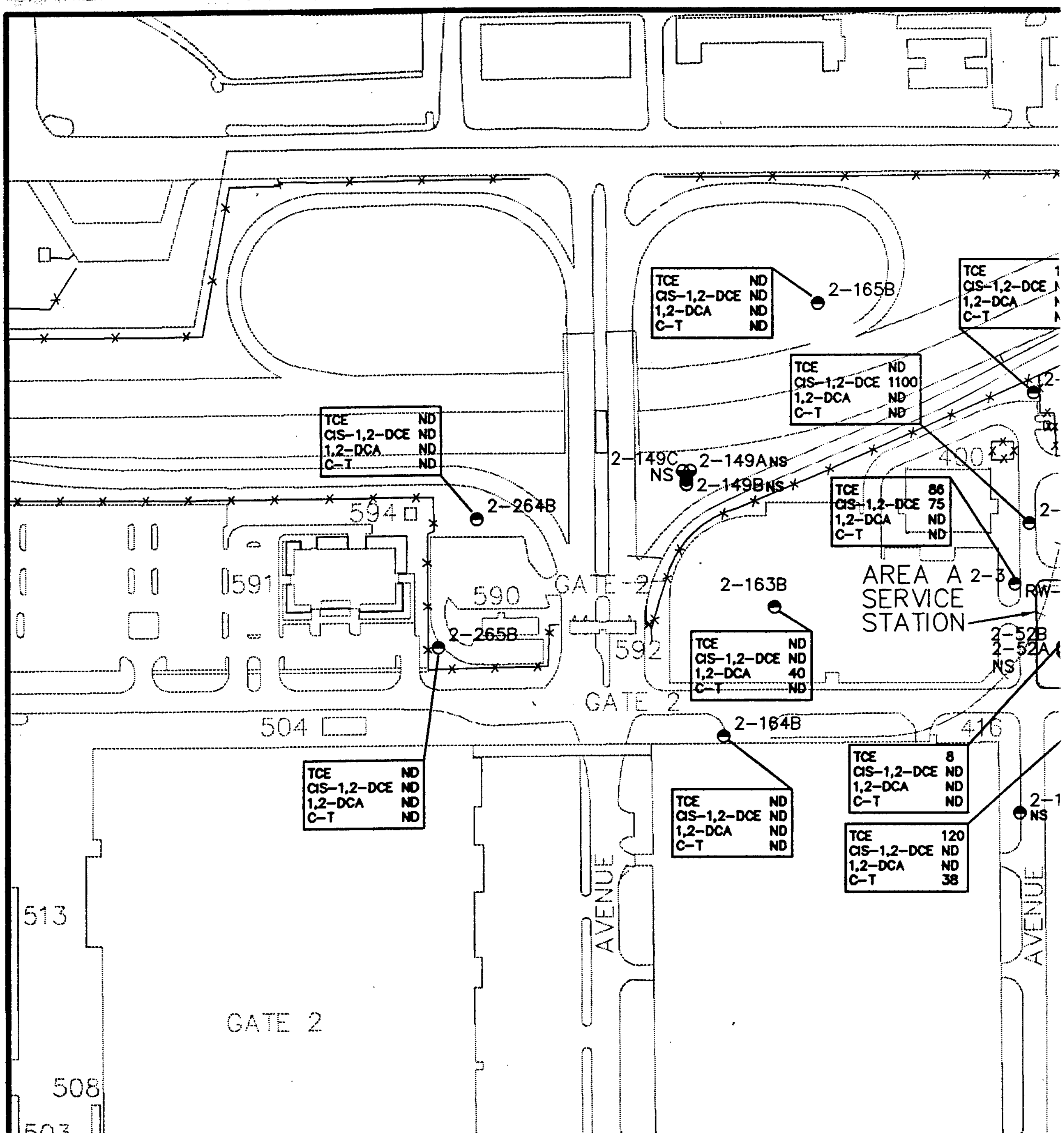
FIGURE 2.17

TOTAL BTEX CONCENTRATIONS IN UPPER SATURATED ZONE AREA A SERVICE STATION

Sites FTA 2 and Area A
RNA TS
Tinker AFB, Oklahoma

PARSONS ENGINEERING SCIENCE, INC.

Denver, Colorado



LEGEND

2-165B	UPPER SATURATED ZONE MONITORING WELL LOCATION AND ID NUMBER	TCE	TRICHLOROETHENE
2-2A	LOWER SATURATED ZONE MONITORING WELL LOCATION AND ID NUMBER	CIS-1,2-DCE	CIS – 1,2 – DICHLOROETHENE
RW-1	PRODUCT RECOVERY WELL	1,2-DCA	1,2 – DICHLOROETHANE
WS-32	WATER SUPPLY WELL	C-T	CARBON TETRACHLORIDE
		NS	NOT SAMPLED
		ND	NOT DETECTED

ALL CONCENTRATIONS IN MICROGRAMS PER LITER (μ

1

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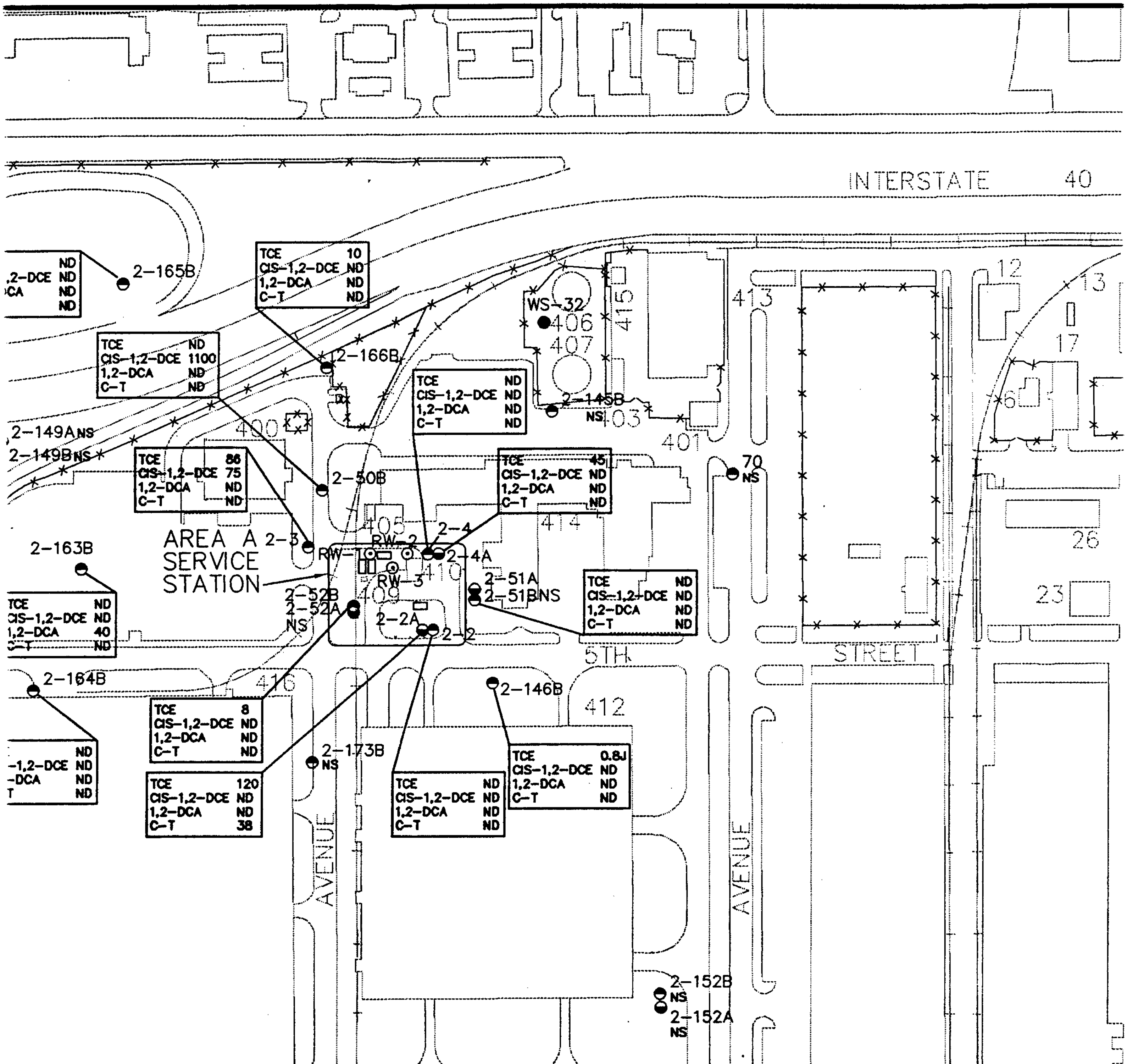

TRICHLOROETHENE

-1,2-DCE CIS – 1,2 – DICHLOROETHENE

-DCA 1,2 – DICHLOROETHANE

CARBON TETRACHLORIDE

NOT SAMPLED

NOT DETECTED

CONCENTRATIONS IN MICROGRAMS PER LITER ($\mu g/L$)

N

0 100 200 400

FEET

2

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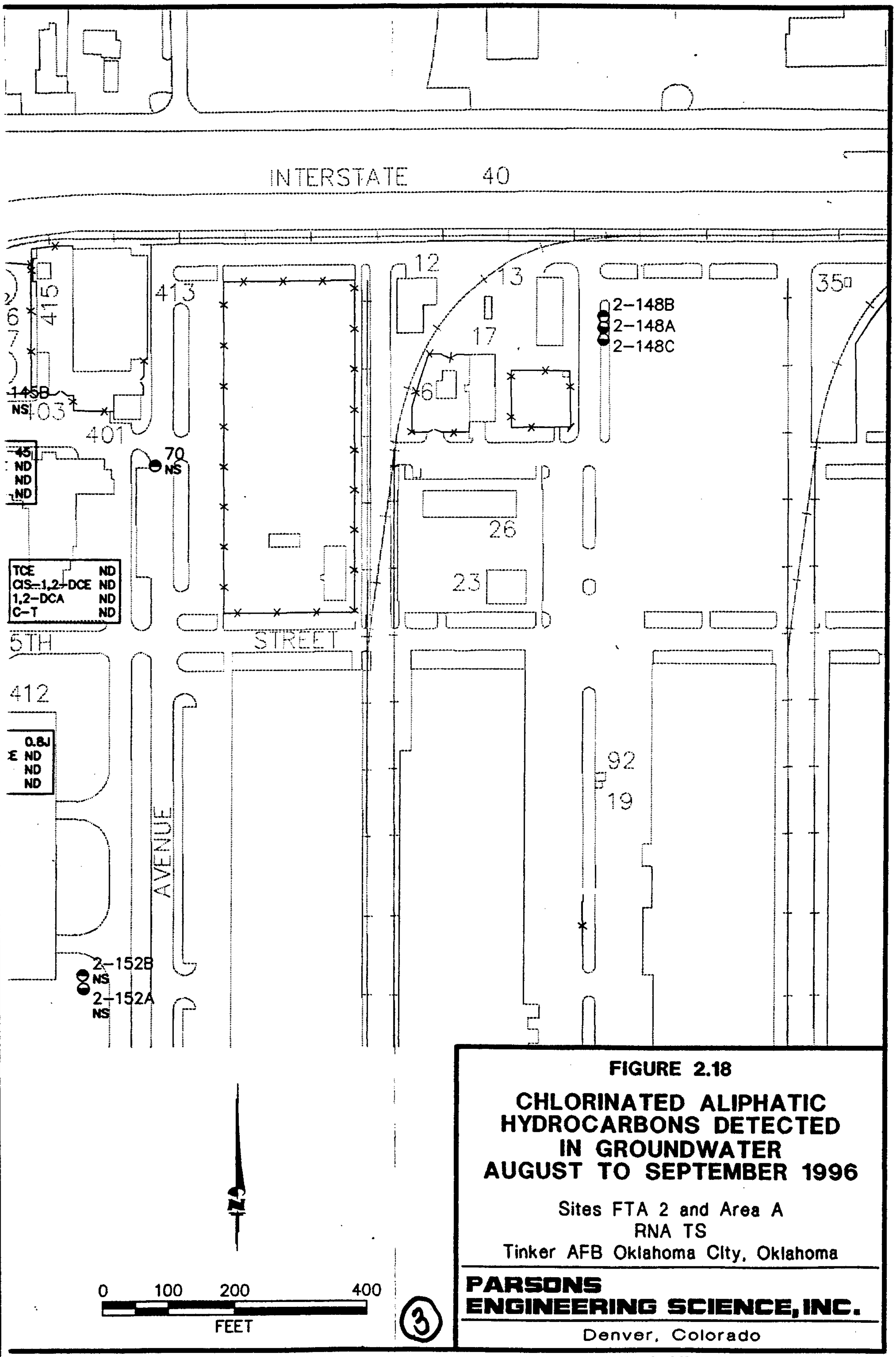

FIGURE 2.18

CHLORINATED ALIPHATIC HYDROCARBONS DETECTED IN GROUNDWATER AUGUST TO SEPTEMBER 1996

Sites FTA 2 and Area A
RNA TS
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In the LSZ, only the chlorinated solvents TCE and carbon tetrachloride were detected in August and September 1996 at concentrations of 120 μg/L and 38 μg/L, respectively, in the groundwater sample from well 2-2A. However, only data for two LSZ monitoring wells are available from that sampling event. Other chlorinated solvents detected in earlier sampling events include low concentrations (less than 2 μg/L) of PCE, *cis*-1,2-DCE, *trans*-1,2-DCE, and 1,2-DCA.

Only BTEX compounds and organic solvents are included as part of this RNA demonstration; therefore, results for other potential contaminants such as herbicides, PAHs, PCBs, pesticides, or metals are not summarized in this work plan. These compounds have been addressed in previous reports. Information on these compounds is presented by ERI (1990), WSCI (1992), and IT (1996).

2.2 DEVELOPMENT OF CONCEPTUAL MODELS

A conceptual model is a three-dimensional representation of a hydrogeologic system based on available geological, hydrological, climatological, and geochemical data. A site-specific conceptual model is developed to provide an understanding of the mechanisms controlling contaminant fate and transport and to identify additional data requirements. The model describes known and suspected sources of contamination, types of contamination, affected media, contaminant migration pathways, and potential receptor exposure points. The model also provides a foundation for formulating decisions regarding additional data collection and potential remedial actions. The conceptual models for FTA 2 and Area A will be used to aid in selecting additional data collection points and to identify appropriate data needs for modeling BTEX and chlorinated solvent attenuation using groundwater flow and solute transport models.

Successful conceptual model development involves:

- Defining the problem to be solved;

- Integrating available data, including
  - Local geologic and topographic data,
  - Hydraulic data,
  - Site stratigraphic data, and
  - Contaminant concentration and distribution data;
- Evaluating contaminant fate and transport characteristics;
- Identifying contaminant migration pathways;
- Identifying potential receptors and receptor exposure points; and
- Determining additional data requirements.

2.2.1 RNA and Groundwater Flow and Solute Transport Models

The positive effect of natural attenuation processes (e.g., advection, dispersion, sorption, and biodegradation) on reducing the actual mass of fuel-related contamination dissolved in groundwater has been termed RNA. To estimate the impact of natural attenuation on the fate and transport of BTEX and CAH compounds dissolved in groundwater at a site, two important lines of evidence must be demonstrated (Wiedemeier *et al.*, 1995). The first is a documented loss of contaminants at the field scale. One way to show loss of contaminant mass is to use historical monitoring data to show that plume concentrations and extents decrease or remain stable over time. At some sites, dissolved concentrations of biologically recalcitrant tracers found in most fuel contamination can be used in conjunction with aquifer hydrogeologic parameters, such as groundwater seepage velocity and dilution, to demonstrate that a reduction in contaminant mass is occurring. The second line of evidence involves the use of geochemical data to show that areas with dissolved BTEX and CAH contamination can

be correlated to areas with depleted electron acceptor (e.g., oxygen, nitrate, and sulfate) concentrations and increases in metabolic degradation byproduct concentrations (e.g., methane, ferrous iron, ethene, and chloride). With this site-specific information, groundwater flow and solute transport models can be used to simulate the fate and transport of dissolved BTEX and CAH compounds under the influence of natural attenuation.

Groundwater flow and solute transport models have proven useful for predicting plume migration and contaminant attenuation by natural biodegradation. Analytical and numerical models are available for modeling the fate and transport of BTEX and CAHs under the influence of advection, dispersion, sorption, and natural aerobic and anaerobic biodegradation. Analytical models derived from advection-dispersion equations [e.g., models such as those presented by Wexler (1992) and van Genuchten and Alves (1982)] may be useful. However, because BTEX and CAH biodegradation may be the result of different processes in different locations, it may be necessary to use a numerical model to incorporate spatial variability into the fate and transport analysis.

An accurate estimate of the potential for natural biodegradation of CAHs and BTEX compounds in groundwater is important to consider when determining whether groundwater contamination presents a substantial threat to human health and the environment, and when deciding what type of remedial alternative will be most cost effective in eliminating or abating these threats. Over the past two decades, numerous laboratory and field studies have demonstrated that subsurface microorganisms can degrade a variety of hydrocarbons and chlorinated solvents (Lee, 1988; McCarty *et al.*, 1992). The following sections discuss the biodegradation of BTEX and CAHs.

2.2.2 Biodegradation of Dissolved BTEX Contamination

Numerous laboratory and field studies have shown that hydrocarbon-degrading bacteria can participate in the degradation of many of the chemical components of fuel hydrocarbons, including the BTEX compounds (e.g., Jamison *et al.,* 1975; Atlas, 1981, 1984, 1988; Gibson and Subramanian, 1984; Reinhard *et al.,* 1984; Young, 1984; Bartha, 1986; Wilson *et al.,* 1986, 1987, and 1990; Barker *et al.,* 1987; Baedecker *et al.,* 1988; Lee, 1988; Chiang *et al.,* 1989; Grbic-Galic, 1989 and 1990; Cozzarelli *et al.,* 1990; Leahy and Colewell, 1990; Altenschmidt and Fuchs, 1991; Alvarez and Vogel, 1991; Baedecker and Cozzarelli, 1991; Ball *et al.,* 1991; Bauman, 1991; Borden, 1991; Brown *et al.*, 1991; Edwards *et al.,* 1991 and 1992; Evans *et al.,* 1991a and 1991b; Haag *et al.,* 1991; Hutchins and Wilson, 1991; Hutchins *et al.,* 1991a and 1991b; Beller *et al.,* 1992; Bouwer, 1992; Edwards and Grbic-Galic, 1992; Edwards *et al.,* 1992; Thierrin *et al.,* 1992; Malone *et al.,* 1993; Davis *et al.,* 1994). Biodegradation of fuel hydrocarbons can occur when an indigenous population of hydrocarbon-degrading microorganisms is present in the aquifer and sufficient concentrations of electron acceptors and nutrients, including fuel hydrocarbons, are available to these organisms.

Microorganisms obtain energy for cell production and maintenance by facilitation of thermodynamically advantageous reduction/oxidation (redox) reactions involving the transfer of electrons from electron donors to available electron acceptors. This results in the oxidation of the electron donor and the reduction of the electron acceptor. Electron donors at FTA 2 and Area A may include natural organic carbon and fuel hydrocarbon compounds. Fuel hydrocarbons are completely degraded or detoxified if they are utilized as the primary electron donor for microbial metabolism (Bouwer, 1992). Electron acceptors are elements or compounds that occur in relatively oxidized states, and include dissolved oxygen (DO), nitrate, ferric iron, sulfate, and carbon dioxide.

The driving force of BTEX degradation is electron transfer, which is quantified by the Gibbs free energy of the reaction (ΔG°_{r}) (Stumm and Morgan, 1981; Bouwer, 1994; Godsey, 1994). The value of ΔG°_{r} represents the quantity of free energy consumed or yielded to the system during the reaction. Table 2.6 lists stoichiometry of the redox equations involving BTEX and the resulting ΔG°_{r}. Although thermodynamically favorable, most of the reactions involved in BTEX oxidation cannot proceed abiotically because of the lack of activation energy. Microorganisms are capable of providing the necessary activation energy; however, they will facilitate only those redox reactions that have a net yield of energy (i.e., $\Delta G^{\circ}_{r} < 0$). Microorganisms preferentially utilize electron acceptors while metabolizing fuel hydrocarbons (Bouwer, 1992). DO is utilized first as the prime electron acceptor. After the DO is consumed, anaerobic microorganisms typically use electron acceptors (as available) in the following order of preference: nitrate, ferric iron hydroxide, sulfate, and finally carbon dioxide. Because the biodegradation of fuel hydrocarbons should deplete the concentrations of these electron acceptors, construction of isopleth maps depicting their concentrations can provide evidence of whether biodegradation is occurring, and the degree to which it is occurring.

Depending on the types and concentrations of electron acceptors present (e.g., nitrate, ferric iron, sulfate, carbon dioxide), pH conditions, and redox potential, anaerobic biodegradation can occur by denitrification, ferric iron reduction, sulfate reduction, or methanogenesis. Other, less common anaerobic degradation mechanisms such as manganese or nitrate reduction may dominate if the physical and chemical conditions in the subsurface favor use of these electron acceptors. Anaerobic destruction of BTEX compounds is associated with the accumulation of fatty acids, production of methane, solubilization of iron, and reduction of nitrate and sulfate (Cozzarelli *et al.*, 1990; Wilson *et al.*, 1990). Environmental conditions and microbial competition will ultimately determine which processes will dominate. Vroblesky and

TABLE 2.6
COUPLED OXIDATION REACTIONS FOR BTEX COMPOUNDS
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Coupled Benzene Oxidation Reactions	ΔG°r (kcal/mole Benzene)	ΔG°r (kJ/mole Benzene)	Stoichiometric Mass Ratio of Electron Acceptor to Compound
$7.5O_2 + C_6H_6 \Rightarrow 6CO_{2,g} + 3H_2O$ *Benzene oxidation /aerobic respiration*	-765.34	-3202	3.07:1
$6NO_3^- + 6H^+ + C_6H_6 \Rightarrow 6CO_{2,g} + 6H_2O + 3N_{2,g}$ *Benzene oxidation / denitrification*	-775.75	-3245	4.77:1
$3.75\ NO_3^- + C_6H_6 + 7.5\ H^+ + 0.75\ H_2O \Rightarrow 6\ CO_2 + 3.75\ NH_4^+$ *Benzene oxidation / nitrate reduction*	-524.1	-2193	2.98:1
$60H^+ + \underline{30Fe(OH)_{3,a}} + C_6H_6 \Rightarrow 6CO_2 + 30Fe^{2+} + 78H_2O$ *Benzene oxidation / iron reduction*	-560.10	-2343	21.5:1 [a/]
$7.5H^+ + 3.75SO_4^{2-} + C_6H_6 \Rightarrow 6CO_{2,g} + 3.75H_2S^o + 3H_2O$ *Benzene oxidation / sulfate reduction*	-122.93	-514.3	4.61:1
$4.5H_2O + C_6H_6 \Rightarrow 2.25CO_{2,g} + 3.75CH_4$ *Benzene oxidation / methanogenesis*	-32.40	-135.6	0.77:1 [b/]

Coupled Toluene Oxidation Reactions	ΔG°r (kcal/mole Toluene)	ΔG°r (kJ/mole Toluene)	Stoichiometric Mass Ratio of Electron Acceptor to Compound
$9O_2 + C_6H_5CH_3 \Rightarrow 7CO_{2,g} + 4H_2O$ *Toluene oxidation /aerobic respiration*	-913.76	-3823	3.13:1
$7.2NO_3^- + 7.2H^+ + C_6H_5CH_3 \Rightarrow 7CO_{2,g} + 7.6H_2O + 3.6N_{2,g}$ *Toluene oxidation / denitrification*	-926.31	-3875	4.85:1
$72H^+ + \underline{36Fe(OH)_{3,a}} + C_6H_5CH_3 \Rightarrow 7CO_2 + 36Fe^{2+} + 94H_2O$ *Toluene oxidation / iron reduction*	-667.21	-2792	21.86:1 [a/]
$9H^+ + 4.5SO_4^{2-} + C_6H_5CH_3 \Rightarrow 7CO_{2,g} + 4.5H_2S^o + 4H_2O$ *Toluene oxidation / sulfate reduction*	-142.86	-597.7	4.7:1
$5H_2O + C_6H_5CH_3 \Rightarrow 2.5CO_{2,g} + 4.5CH_4$ *Toluene oxidation / methanogenesis*	-34.08	-142.6	0.78:1 [b/]

TABLE 2.6 (Continued)
COUPLED OXIDATION REACTIONS FOR BTEX COMPOUNDS
SITES FTA 2 AND AREA A
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Coupled Ethylbenzene Oxidation Reactions	ΔG°_{r} (kcal/mole Ethyl-benzene)	ΔG°_{r} (kJ/mole Ethyl-benzene)	Stoichiometric Mass Ratio of Electron Acceptor to Compound
$10.5 O_2 + C_6H_5C_2H_5 \Rightarrow 8CO_{2,g} + 5H_2O$ *Ethylbenzene oxidation /aerobic respiration*	-1066.13	-4461	3.17:1
$8.4 NO_3^- + 8.4H^+ + C_6H_5C_2H_5 \Rightarrow 8CO_{2,g} + 9.2H_2O + 4.2N_{2,g}$ *Ethylbenzene oxidation / denitrification*	-1080.76	-4522	4.92:1
$84H^+ + 42\underline{Fe(OH)_{3,a}} + C_6H_5C_2H_5 \Rightarrow 8CO_2 + 42Fe^{2+} + 110H_2O$ *Ethylbenzene oxidation / iron reduction*	-778.48	-3257	22:1[a]
$10.5H^+ + 5.25SO_4^{2-} + C_6H_5C_2H_5 \Rightarrow 8CO_{2,g} + 5.25H_2S^o + 5H_2O$ *Eth ylbenzene oxidation / sulfate reduction*	-166.75	-697.7	4.75:1
$5.5H_2O + C_6H_5C_2H_5 \Rightarrow 2.75CO_{2,g} + 5.25CH_4$ *Ethylbenzene oxidation / methanogenesis*	-39.83	-166.7	0.79:1 [b]

Coupled m-Xylene Oxidation Reactions	ΔG°_{r} (kcal/mole *m*-xylene)	ΔG°_{r} (kJ/mole *m*-xylene)	Stoichiometric Mass Ratio of Electron Acceptor to Compound
$10.5 O_2 + C_6H_4(CH_3)_2 \Rightarrow 8CO_{2,g} + 5H_2O$ *m-Xylene oxidation /aerobic respiration*	-1063.25	-4448	3.17:1
$8.4 NO_3^- + 8.4H^+ + C_6H_4(CH_3)_2 \Rightarrow 8CO_{2,g} + 9.2H_2O + 4.2N_{2,g}$ *m-Xylene oxidation / denitrification*	-1077.81	-4509	4.92:1
$84H^+ + 42\underline{Fe(OH)_{3,a}} + C_6H_4(CH_3)_2 \Rightarrow 8CO_2 + 42Fe^{2+} + 110H_2O$ *m-Xylene oxidation / iron reduction*	-775.61	-3245	22:1[a]
$10.5H^+ + 5.25SO_4^{2-} + C_6H_4(CH_3)_2 \Rightarrow 8CO_{2,g} + 5.25H_2S^o + 5H_2O$ *m-Xylene oxidation / sulfate reduction*	-163.87	-685.6	4.75:1
$5.5H_2O + C_6H_4(CH_3)_2 \Rightarrow 2.75CO_{2,g} + 5.25CH_4$ *m-Xylene oxidation / methanogenesis*	-36.95	-154.6	0.79:1 [b]

[a/] Mass of ferrous iron produced during microbial respiration.

[b/] Mass of methane produced during microbial respiration.

Chapelle (1994) show that the dominant terminal electron accepting process can vary both temporally and spatially in an aquifer with fuel hydrocarbon contamination.

2.2.3 Biodegradation of CAHs

Chlorinated solvents can be transformed, directly or indirectly, by biological processes (e.g., Bouwer *et al.*, 1981; Wilson and Wilson, 1985; Miller and Guengerich, 1982; Nelson *et al.*, 1986; Bouwer and Wright, 1988; Little *et al.*, 1988; Mayer *et al.*, 1988; Arciero *et al.*, 1989; Cline and Delfino, 1989; Freedman and Gossett, 1989; Folsom *et al.*, 1990; Harker and Kim, 1990; Alvarez-Cohen and McCarty, 1991a, 1991b; DeStefano *et al.*, 1991; Henry, 1991; McCarty *et al.*, 1992; Hartmans and de Bont, 1992; McCarty and Semprini, 1994; Vogel, 1994). CAHs may undergo biodegradation through three different pathways: use as an electron acceptor, use as an electron donor, or cometabolism, which is degradation resulting from exposure to a catalytic enzyme fortuitously produced during an unrelated process. At a given site, one or all of these processes may be operating, although at many sites the use of CAHs as electron acceptors appears to be the most important.

In a pristine aquifer, native organic carbon is utilized as an electron donor and dissolved oxygen (DO) is utilized first as the prime electron acceptor. Where anthropogenic carbon (e.g., fuel hydrocarbons or less chlorinated CAHs) is present, it also will be utilized as an electron donor. After the DO is consumed, anaerobic microorganisms typically use native electron acceptors (as available) in the following order of preference: nitrate, ferric iron oxyhydroxide, sulfate, and finally carbon dioxide. Evaluation of the distribution of these electron acceptors can provide evidence of where and how CAH biodegradation is occurring. In addition, because CAHs may be used as electron acceptors or electron donors (in competition with other acceptors or donors), maps showing the distribution of these compounds will also provide evidence on the types of biodegradation processes acting at a site.

As with BTEX, the driving force behind redox reactions resulting in CAH degradation is electron transfer. Although thermodynamically favorable, most of the reactions involved in CAH reduction and oxidation cannot proceed abiotically because of the lack of activation energy. Microorganisms are capable of providing the necessary activation energy; however, they will facilitate only those redox reactions that have a net yield of energy. A more complete description of the main types of biodegradation reactions affecting CAHs is presented in the following subsections.

2.2.3.1 Electron Acceptor Reactions (Reductive Dechlorination)

Under anaerobic conditions, biodegradation of chlorinated solvents usually proceeds through a process called reductive dehalogenation. During this process, the halogenated hydrocarbon is used as an electron acceptor, not as a source of carbon, and a halogen atom is removed and replaced with a hydrogen atom. Figure 2.19 illustrates the transformation of chlorinated ethenes via reductive dehalogenation. In general, reductive dehalogenation occurs by sequential dechlorination from PCE to TCE to DCE to VC to ethene. Depending upon environmental conditions, this sequence may be interrupted, with other processes then acting upon the products. During reductive dehalogenation, all three isomers of DCE can theoretically be produced; however, Bouwer (1994) reports that under the influence of biodegradation, *cis*-1,2-DCE is a more common intermediate than *trans*-1,2-DCE, and that 1,1-DCE is the least prevalent intermediate of the three DCE isomers. Reductive dehalogenation of chlorinated solvent compounds is associated with the accumulation of daughter products and an increase in chloride.

Reductive dehalogenation affects each of the chlorinated ethenes differently. PCE is the most susceptible of these compounds to reductive dehalogenation because it is the most oxidized. Conversely, VC is the least susceptible to reductive dehalogenation

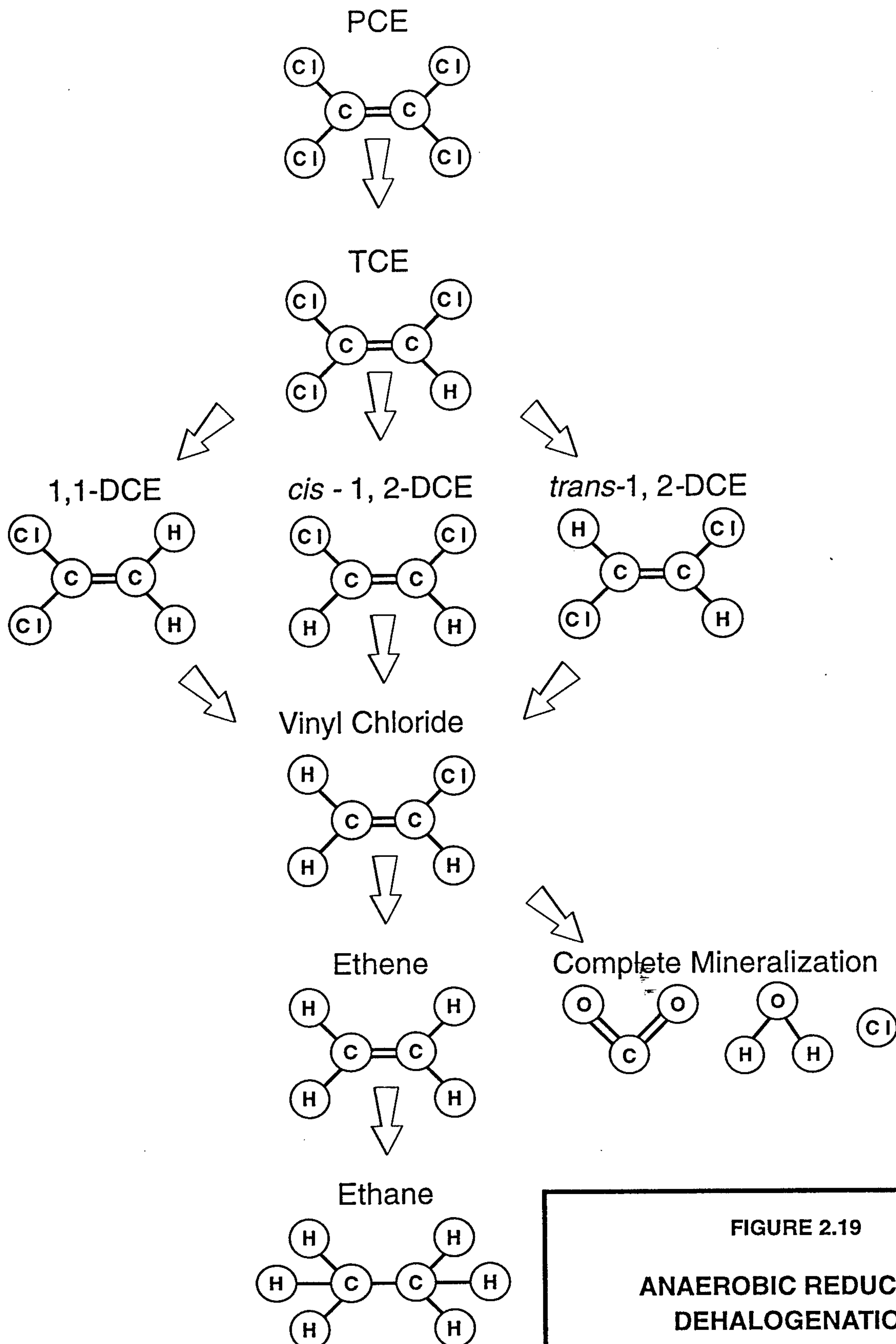

FIGURE 2.19

ANAEROBIC REDUCTIVE DEHALOGENATION

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because it is the least oxidized of these compounds. The rate of reductive dehalogenation also has been observed to decrease as the degree of chlorination decreases (Vogel and McCarty, 1985; Bouwer, 1994). Murray and Richardson (1993) have postulated that this rate decrease may explain the accumulation of VC in PCE and TCE plumes that are undergoing reductive dechlorination. Reductive dehalogenation has been demonstrated under nitrate- and sulfate-reducing conditions, but the most rapid biodegradation rates, affecting the widest range of CAHs, occur under methanogenic conditions (Bouwer, 1994).

Because CAH compounds are used as electron acceptors, there must be an appropriate source of carbon for microbial growth in order for reductive dehalogenation to occur (Bouwer, 1994). Potential carbon sources can include low-molecular-weight compounds (e.g., lactate, acetate, methanol, or glucose) present in natural organic matter, fuel hydrocarbons, or less-chlorinated compounds such as VC, DCE, or DCA.

2.2.3.2 Electron Donor Reactions

Under aerobic conditions some CAH compounds can be utilized as the primary substrate (i.e., electron donor) in biologically mediated redox reactions (McCarty and Semprini, 1994). In this type of reaction, the facilitating microorganism obtains energy and organic carbon from the degraded CAH. In contrast to reactions in which the CAH is used as an electron acceptor, only the least oxidized CAHs can be utilized as electron donors in biologically mediated redox reactions. McCarty and Semprini (1994) describe investigations in which VC and 1,2-dichloroethane (DCA) were shown to serve as primary substrates. These authors also document that dichloromethane has the potential to function as a primary substrate in either aerobic or anaerobic environments. In addition, Bradley and Chapelle (1996) show evidence of mineralization of VC under iron-reducing conditions so long as there is sufficient bioavailable iron (III). Klier *et al.*, (1996) demonstrated aerobic mineralization of all 3

isomers of DCE. Murray and Richardson (1993) write that microorganisms are generally believed to be incapable of growth using TCE and PCE. Aerobic metabolism of VC, DCA, or DCE may be characterized by a loss of VC, DCA, or DCE mass or a decreasing molar ratio of VC, DCA, or DCE to other CAH compounds.

2.2.3.3 Cometabolism

When a CAH is biodegraded through cometabolism, it serves as neither an electron acceptor nor a primary substrate in a biologically mediated redox reaction. Instead, the degradation of the CAH is catalyzed by an enzyme or cofactor that is fortuitously produced by organisms for other purposes. The organism receives no known benefit from the degradation of the CAH; rather the cometabolic degradation of the CAH may in fact be harmful to the microorganism responsible for the production of the enzyme or cofactor (McCarty and Semprini, 1994).

Cometabolism is best documented in aerobic environments, although it potentially could occur under anaerobic conditions. Aerobic biodegradation pathways for chlorinated ethenes are illustrated in Figure 2.20. It has been reported that under aerobic conditions chlorinated ethenes, with the exception of PCE, are susceptible to cometabolic degradation (Murray and Richardson, 1993; Vogel, 1994; McCarty and Semprini, 1994). Vogel (1994) further elaborates that the cometabolism rate increases as the degree of dechlorination decreases.

During the cometabolic process, TCE is indirectly transformed by bacteria as an organic carbon substrate is used to meet their energy requirements. Therefore, TCE does not enhance the degradation of carbon sources, nor will its cometabolism interfere with the use of electron acceptors involved in the oxidation of those carbon sources. It is likely that depletion of suitable substrates (organic carbon sources) may limit cometabolism of CAHs.

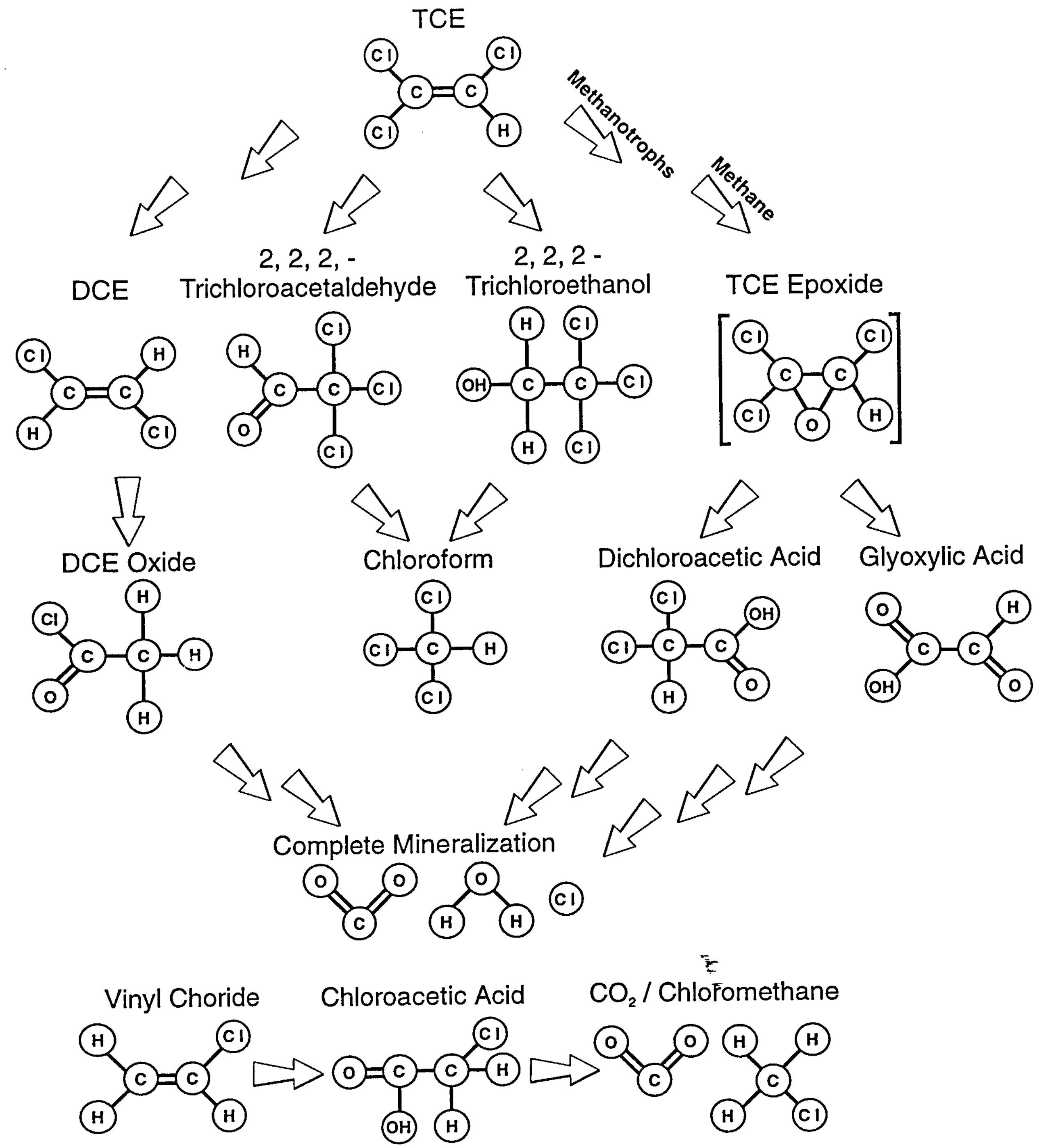

FIGURE 2.20

AEROBIC BIODEGRADATION PATHWAYS

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2.2.3.4 Behavior of Chlorinated Solvent Plumes

Chlorinated solvent plumes can exhibit three types of behavior depending on the amount of solvent, the amount of organic (native and/or anthropogenic) organic carbon in the aquifer, the distribution and concentration of natural electron acceptors, and the types of electron acceptors being utilized. Individual plumes may exhibit all three types of behavior in different portions of the plume. The different types of plume behavior are summarized below.

2.2.3.4.1 Type 1 Behavior

Type 1 behavior occurs where the primary substrate is anthropogenic carbon (e.g., BTEX or landfill leachate) and this anthropogenic carbon drives reductive dechlorination. When evaluating RNA of a plume exhibiting type 1 behavior the following questions must be answered:

1. Does electron acceptor supply exceed demand (i.e., is the electron acceptor supply adequate)? Will the microorganisms degrading the CAH plume strangle before they starve [i.e., will they run out of CAHs (electron acceptors) before they run out of primary substrate (anthropogenic carbon)]?

2. What is the role of competing electron acceptors?

3. Are VC and DCE oxidized or reduced?

2.2.3.4.2 Type 2 Behavior

Type 2 behavior dominates in areas that are characterized by relatively high native organic carbon concentrations, and this carbon source drives reductive dechlorination (i.e., the primary substrate for microorganism growth is native organic carbon). When evaluating RNA of a type 2 chlorinated solvent plume, the same questions as those posed in the description of type 1 behavior must be answered.

2.2.3.4.3 Type 3 Behavior

Type 3 behavior dominates in areas that are characterized by low native and/or anthropogenic carbon concentrations where dissolved oxygen concentrations are greater than 1.0 milligrams per liter (mg/L). Under these conditions the plume is aerobic and reductive dechlorination will not occur. Thus there is no biodegradation of PCE and TCE, and natural attenuation mechanisms for these compounds are advection, dispersion, and sorption only. However, VC, DCA, and DCE can be oxidized under these conditions.

2.2.3.4.4 Mixed Behavior

As mentioned above, a single chlorinated solvent plume can exhibit all three types of behavior in different portions of the plume. This can be beneficial for natural biodegradation of CAH plumes. For example Wiedemeier *et al.* (1996b) describe a plume at Plattsburgh AFB, New York that exhibits type 1 behavior in the source area and type 3 behavior downgradient from the source. The best scenario involves a plume in which TCE and DCE are reductively dechlorinated (type 1 or 2 behavior), then VC is oxidized (type 3 behavior), either aerobically or anaerobically (via iron reduction). Vinyl chloride is oxidized to carbon dioxide in this type of plume and does not accumulate. The following sequence of reactions occurs in this type of plume.

$$TCE \rightarrow DCE \rightarrow VC \rightarrow CO_2$$

In general, the TCE, DCE, and VC are attenuated at approximately the same rate, and thus these reactions may be confused with simple dilution. Note that no ethene is produced during this reaction. Vinyl chloride is removed from the system much faster under these conditions than it is under VC-reducing conditions.

A less desirable scenario involves a plume in which all CAHs are reductively dechlorinated (type 2 or 3 behavior). Vinyl chloride is reduced to ethene which is

further reduced to ethane. The following sequence of reactions occur in this type of plume.

$$TCE \rightarrow DCE \rightarrow VC \rightarrow Ethene \rightarrow Ethane$$

In this type of plume, DCE and VC degrade more slowly than TCE, and thus they tend to accumulate. This is the type of reductive dechlorination described by Freedman and Gossett (1989).

2.2.4 Initial Conceptual Model

2.2.4.1 Initial Conceptual Model for FTA 2

Geologic and hydrogeologic data for FTA 2 were previously integrated to produce a geologic cross-section of the site (Figure 2.7). The cross-section shown on Figure 2.7 illustrates the stratigraphy through the site form north to south, perpendicular to the direction of groundwater flow in both the USZ and the LSZ.

Figure 2.8 is a groundwater contour map of the USZ for FTA 2 prepared using September 1996 groundwater elevation data. Groundwater is present approximately 7 to 25 feet bgs. The groundwater flow direction for the USZ at FTA 2 is generally west to southwest. Figure 2.9 is a groundwater contour map of the LSZ for September 1996. The LSZ receives limited vertical recharge due to the aquitard of clay and hard silt deposits below the shallow sand and gravel USZ aquifer. On the basis of available data, Parsons ES will model this site as an unconfined, fine-grained sand aquifer in the USZ, with an unconfined to semi-confined, fine-grained sand lower aquifer (LSZ), separated from the USZ by an semi-confining aquitard of hard silt and clay. This conceptual model will be modified as necessary as additional site hydrogeologic data become available.

Given available information, it appears that the CAH plume originating at FTA 2 is a Type 2 or mixed (Type 2 and Type 3) behavior plume. Residual fuel hydrocarbons from fire training exercises, including TPH, may provide the area with a source of carbon; however with the existing data no conclusions can be drawn. Biodegradation of TCE to 1,2-DCE (primarily the *cis* isomer) appears to be occurring, but the scarcity of other degradation products such as VC indicates that the degradation process has not proceeded further. The relatively high concentrations of *cis*-1,2-DCE and high ratios of *cis*-1,2-DCE to *trans*-1,2-DCE near the TCE source area (well 2-62B) indicate that biodegradation is occurring in that area. There is limited geochemical data for electron acceptor concentrations. Nevertheless, conditions appear to be sufficient for limited reductive dehalogenation of TCE in the source area.

For the purposes of this demonstration, CAHs are the chemicals of concern in groundwater at Site FTA 2 (Table 2.4 and Figures 2.14 and 2.15) and will be the primary focus of this RNA study because of their regulatory importance. The effects of fate and transport processes on the dissolved CAHs will be investigated using quantitative groundwater analytical data and analytical solute-transport models. Data collection and analysis requirements are discussed in Section 3 of this work plan.

2.2.4.2 Initial Conceptual Model for Area A

The Area A geologic data were previously integrated to produce hydrogeologic cross-sections of the site (Figures 2.10 and 2.11). The cross-section shown on Figure 2.10 illustrates the stratigraphy through the site from north to south. The cross-section shown on Figure 2.11 illustrates the stratigraphy through the site from east to west, the primary direction of groundwater flow in both the USZ and the LSZ.

Shallow groundwater (USZ) is encountered at approximately 8 to 19 feet bgs at Area A, and the groundwater flow direction is west to southwest. The LSZ receives limited recharge due to the confining to semi-confining aquitard layer of clay and hard silt

deposits below the shallow sand USZ. On the basis of available data, Parsons ES will model this site as an unconfined, fine-grained sand aquifer in the USZ, with an unconfined fine-grained sand lower aquifer (LSZ), separated from the USZ by an semi-confining aquitard of hard silt and clay. This conceptual model will be modified as necessary as additional site hydrogeologic data become available.

Mobile LNAPL (free product) may be encountered at Area A. If mobile LNAPL is encountered, it may be necessary to use the fuel/water partitioning models of Bruce *et al.* (1991) or Cline *et al.* (1991) to provide a conservative source term to model the partitioning of BTEX (and possible cosolvenated CAH compounds) from the free-phase product into the groundwater. In order to use one of these models, samples of free product will be collected and analyzed for mass fraction of BTEX and CAH. If mobile LNAPL is present, Parsons ES will attempt to collect groundwater samples from immediately below the LNAPL layer, if possible.

For the purposes of this demonstration, BTEX compounds and CAHs are the chemicals of concern in groundwater at Area A (Table 2.5, and Figures 2.16 and 2.17) and will be the primary focus of this RNA study because of their regulatory importance. BTEX is expected to continue to partition from mobile and residual LNAPL in the USZ smear zone into the groundwater, and to migrate downgradient as a dissolved contaminant plume. CAHs are expected to originate and to continue to migrate from an offsite source through the USZ and LSZ beneath Area A. In addition to the effects of mass transport mechanisms (volatilization, dispersion, diffusion, and adsorption), dissolved contaminants will likely be removed from the groundwater system by naturally occurring destructive attenuation mechanisms, such as biodegradation.

Given available information, it is suspected that the CAH plume originating at Area A is a Type 1 behavior plume in the USZ, and a Type 3 or mixed (Type 2 and Type 3)

behavior plume in the LSZ. Fuel hydrocarbons provide the USZ plume with a source of carbon, including elevated concentrations of BTEX. This combination of contaminants in the USZ appears to result in conditions that are favorable for the reductive dehalogenation of CAHs. BTEX contamination is not migrating to the LSZ. If biodegradation is occurring in the LSZ, it is difficult to evaluate because only very low concentrations of DCE have been detected. Furthermore, these concentrations of DCE may be the result of USZ biodegradation followed by migration to the LSZ. There is limited geochemical data for electron acceptor concentrations. Therefore, it is unknown whether groundwater conditions are acceptable for biodegradation of TCE in the LSZ.

The effects of these fate and transport processes on the dissolved groundwater plume will be investigated using the quantitative groundwater analytical data and solute-transport models. Data collection and analysis requirements are discussed in Section 3 of this work plan.

2.2.5 Potential Pathways and Receptors

2.2.5.1 Potential Pathways and Receptors at FTA 2

Precipitation runoff at FTA 2 flows to the storm sewer system. The groundwater at FTA 2 flows generally west-southwest. A light industrial area is present southwest of FTA 2. Some of the monitoring wells associated with FTA 2 are located in the industrial area (Figure 1.3). Because the site is located near an industrial area on a secured military Base, Base workers are the most probable potential receptors that could be exposed to any site-related contamination. Other receptors include Tinker AFB water supply wells located on the western portion of the Base.

2.2.5.2 Potential Pathways and Receptors at Area A

There are two Base water supply wells located approximately 1 mile west of Area A, but both of these wells are screened nearly 400 feet bgs in the confined regional

aquifer. The direction of shallow groundwater flow in the area of Area A is generally west-southwest.

Because the site is near recreational facilities for a secured military Base, Base workers and their families could be exposed to site-related contamination. Water supply well WS-32 is located to the northeast of the Area A Service Station, and is also a potential receptor.

SECTION 3

COLLECTION OF ADDITIONAL DATA

To complete the demonstration and to assess the degree to which RNA of BTEX and CAHs is occurring at Sites FTA 2 and Area A, additional site-specific physical and chemical hydrogeologic data will be collected to supplement the available site data. Many of these measurements and analyses are commonly performed at hazardous waste sites; however, some of the data will be collected specifically to assess the potential for use of RNA for the BTEX and CAHs at FTA 2 and Area A. The following information will be determined from the site investigation:

- Groundwater elevations at site monitoring wells;
- Mobile LNAPL composition, extent, and thickness (at Area A only);
- Concentration and extent of soil and groundwater contamination (analyses listed in Table 3.1);
- Subsurface geochemistry (analyses listed in Table 3.1);
- Locations of potential groundwater recharge and discharge areas;
- Locations of downgradient wells and their uses;
- Hydraulic conductivity through slug tests;
- Stratigraphy of subsurface media; and

TABLE 3.1
ANALYTICAL PROTOCOLS FOR
GROUNDWATER, FREE PRODUCT, AND SOIL SAMPLES
SITES FTA 2 AND AREA A
RNA TS
TINKER AFB, OKLAHOMA

MATRIX Analyte	**METHOD**	**FIELD (F) OR ANALYTICAL LABORATORY (L**
WATER		
Total Iron	Colorimetric, Hach Method 8008 (or similar)	F
Ferrous Iron (Fe^{+2})	Colorimetric, Hach Method 8146 (or similar)	F
Ferric Iron (Fe^{+3})	Difference between total and ferrous iron	F
Manganese	Colorimetric, Hach Method 8034 (or similar)	F
Sulfide	Colorimetric, Hach Method 8131 (or similar)	F
Sulfate	Colorimetric, Hach Method 8051 (or similar)	F
Nitrate	Titrimetric, Hach Method 8039 (or similar)	F
Nitrite	Titrimetric, Hach Method 8507 (or similar)	F
Redox Potential	A2580B, direct-reading meter	F
Oxygen	Direct-reading meter	F
pH	E150.1/SW9040, direct-reading meter	F
Conductivity	E120.1/SW9050, direct-reading meter	F
Temperature	E170.1, direct reading meter	F
Alkalinity (Carbonate [CO_3^{-2}] and Bicarbonate [HCO_3^{-1}])	Titrimetric, Hach Method 8221 (or similar)	F
Carbon Dioxide	Titrimetric, Hach Method 1436-01	F
Nitrate	E353.1	L
Nitrite	E353.1	L
Chloride	Waters Capillary Electrophoresis Method N-601	L
Sulfate	Waters Capillary Electrophoresis Method N-601	L
Alkalinity	E310.1	L
Methane, Ethane, Ethene	RSKSOP-147[a/]	L
Dissolved Organic Carbon	RSKSOP-102	L
VOCs (BTEX, CAHs, chloroform, chloromethane)	RSKSOP-148	L
FREE PRODUCT		
Free Product (BTEX and CAHs)	GS/MS, Direct Injection SW8240B	L
SOIL		
Total Organic Carbon	RSKSOP-102 & RSKSOP-120	L
Moisture	ASTM D-2216	L
VOCs (BTEX + CAHs)	RSKSOP-124, modified	L

[a/]RSKSOP = Robert S. Kerr Laboratory standard operating procedure.

- Locations of preferential groundwater migration pathways and receptor exposure points (if present).

In general, analyses will be performed to allow an inference of which biodegradation processes are ongoing, as well as to provide information useful for solute transport modeling. Some inorganic groundwater chemical parameters [e.g., ferrous iron, DO, or sulfate] are measured to evaluate if there is any ongoing degradation of native or anthropogenic carbon (e.g., BTEX). If such processes are ongoing, they may facilitate degradation of CAHs via the pathways discussed in Section 2.2.3. Chloride data can also be used as an indicator of dechlorination, which can result in increased chloride concentrations in CAH plume interiors. Carbon dioxide data may also indicate biodegradation, as it is the ultimate product of many of the biochemical reaction pathways. Oxidation/reduction potential (ORP) will be measured to help evaluate whether conditions are more suited for biologically mediated reductive dechlorination or oxidation reactions to occur, as well as an indicator parameter for well purging, along with DO, temperature, pH, and conductivity. Methane, ethane, and ethene will be measured for evidence of complete dechlorination of CAHs, while trends in BTEX and CAH concentrations over time can be used to further evaluate the ongoing processes.

Soil analyses will be performed primarily to gain information on the distribution and concentrations of organic carbon, which can aid in sorption or act as an electron donor. However, selected soil samples also will be analyzed for VOCs if field headspace measurements indicate the presence of significant concentrations of VOCs. Additional analyses not listed in Table 3.1 may be performed at the discretion of the Parsons ES, USACE, or USEPA NRMRL scientists working at the site. Additional analytes that may be tested for are listed in Appendix A.

If sufficient product thickness is encountered at Area A, samples of mobile LNAPL will be collected and analyzed for mass fraction of BTEX and CAHs.

Physical hydrogeologic parameters will be measured to further refine the site conceptual models and to aid in assembling and calibrating the groundwater flow portion of a site-specific transport model. To obtain these data, groundwater levels will be measured, and aquifer testing will be conducted. The following sections describe the procedures that will be followed when collecting additional site-specific data.

3.1 SITE MANAGEMENT

The following paragraphs outline site management issues pertaining to the field activities to be conducted at Sites FTA 2 and Area A. Base support, contingency plans, and waste management are discussed.

3.1.1 Base Support

The Base will provide the following support during field activities:

- **Provide Site Access to Field Team Members.** The Base point of contact (POC) will ensure daily access to the sites through arrangements with Tinker AFB security personnel.

- **Coordinate Badge and Vehicle Passes.** The Base POC will coordinate with Tinker AFB security personnel for the issue of personnel badges and vehicle passes for each field team member. Applicable forms will be completed by the Parsons ES field team members. Each field team member will be provided with a badge and vehicle pass (if needed).

- **Provide Flight-Line Drivers Training.** The Base POC will coordinate with Tinker AFB security personnel to provide flight-line drivers training necessary

for work at FTA 2. Each field team member will be provided with flight-line drivers training.

- **Provide Scheduling Information.** The Base POC will notify Parsons ES and USACE of any Base activities that may adversely affect field activities and/or impact the sampling schedule.

- **Provide Base Notification.** The Base POC should ensure that all pertinent parties (e.g., military police, Base Commander's Office) are notified in advance of the drilling and sampling activities.

- **Provide Water Hook-ups and a Central Decontamination Area.** The Base POC will arrange for access to a potable water supply at the site or on the Base for equipment decontamination. In addition, the Base will designate a convenient decontamination area for cleaning equipment. Non-hazardous water wastes from the decontamination area will be transported to a location specified by Base personnel for temporary storage pending coordination of discharge to the Base groundwater treatment plant (GWTP), industrial wastewater treatment plant (IWTP), or sanitary sewer.

- **Provide Access to Office Equipment.** Parsons ES will need access to a telephone with long distance capability and a copy machine to allow for efficient copying of chain-of-custody records and other field forms, as well as distribution of any memos pertaining to site coordination.

- **Assign Accumulation Points.** Any drilling cuttings, well purge fluids, and decontamination rinseate generated during site work that are suspected of being hazardous will be properly contained and moved to predesignated accumulation points for proper disposal.

- **Provide Underground Utility Clearance/Drilling Permits.** Before any work, each proposed intrusive sampling location must be checked for underground utilities by Base personnel or utility representatives, or both. The Base POC will ensure that the field team has written approval before drilling. A copy of clearances will be kept at the site where the drilling work will be conducted. Parsons ES will request clearance of locations at least 10 days before commencement of intrusive site work. The Base will issue digging or other appropriate permits prior to commencement of drilling operations.

3.1.2 Contingency Plans

This subsection describes steps that will be taken by Parsons ES to minimize delays during the investigations. Potential problems that could be encountered during the field effort include:

- Access and coordination difficulties;
- Equipment breakdowns;
- Conflicts with planned sampling locations;
- Abnormal site conditions (e.g., severe weather, unexpected Base operations); and/or
- Drilling permit delays.

3.1.2.1 Access and Coordination Contingencies

Anticipated support needs are outlined in Section 3.1.1. In the event that site access difficulties arise, the Base POC will be contacted to resolve the problem. The Base POC also will be notified if additional support needs arise during the field effort. The Parsons ES site manager and field team leader will be responsible for notifying the

Base POC and/or other designated personnel (e.g., designated site escorts/contacts) of access or coordination difficulties.

3.1.2.2 Equipment Contingencies

In the event of operation problems with field equipment or testing instruments, the following actions will be taken:

- Contact the field team leader;
- Refer to the instrument's instruction book for troubleshooting procedures; and
- Contact the manufacturer and/or supplier.

If necessary, backup instruments will be obtained. However, any such decisions will be made by the Parsons ES site manager after consideration of other potential solutions. Equipment will be maintained and extra batteries and other standard replacement will be carried in order to avoid downtime due to minor problems.

3.1.2.3 Sampling Location Contingencies

During the field effort, certain chosen sampling locations may be inaccessible due to site conditions. When the conditions can be adjusted (e.g., unlocking a gate or moving a vehicle), the Parsons ES site manager and/or field team leader, or USACE field team leader will contact the Base POC and/or site escort to arrange for access to the sampling location. When the sampling location remains inaccessible (e.g., due to overhead wires or underground cables), a new sampling location will be selected as close as possible to the originally designated location. If all areas in the vicinity of the sampling location are affected, the Parsons ES site manager or Parsons ES project manager will contact the Base POC to determine the next best nearby location, or revise the sampling strategy.

3.1.2.4 Abnormal Site Condition Contingencies

If abnormal site conditions are encountered that adversely affect site activities, the following actions will be taken:

- The Base POC will be notified of the conditions (e.g., mowing grass, unexpected construction).
- If the abnormal site conditions cannot be altered, an alternative sampling site will be selected.
- If the abnormal site conditions affect all sampling locations and/or if moving to another sampling site will adversely impact the project schedule or cost, both the Base POC and the AFCEE POC will be notified. A decision will then be made as to the best course of action to ensure quality project completion in a timely and cost-effective manner. Abnormal or unanticipated site conditions that adversely affect personnel health and safety are covered in the program Health and Safety Plan (Parsons ES, 1996).

3.1.2.5 Drilling Permit Delays

To ensure that drilling permits are issued prior to the planned drilling dates, the following Base procedure will be followed. Parsons ES personnel will identify drilling locations at the time of the kickoff meeting with pin flags, flagging tape, or fluorescent paint. A drawing indicating the locations and depths of the proposed drilling activities will be provided to the Base POC by Parsons ES at least 10 days prior to sampling activities. Civil Engineering and/or utility personnel will locate underground utility lines and buried structures that might be affected by any drilling prior to mobilization. No drilling will be allowed until the permit is approved by all parties. The drilling permit will be effective only for the time period indicated by the final signature authority. Reauthorization from all organizations and the technical representative shall

be required for any additional time required after expiration of the original permit period.

3.1.2.6 Site Health and Safety Plan

Parsons ES will provide a Health and Safety Plan (Parsons ES, 1996) and a site-specific addendum for field investigations to be conducted at Tinker AFB. The documents will be provided to the Base POC for review prior to field mobilization, if requested by the Base POC. The plan includes the following information:

- An index of all hazardous materials to be introduced to the site;
- Plan for protecting personnel and property during the transport, storage and use of the materials;
- Procedures for spill response and disposal;
- Material safety data sheets (MSDSs) for materials listed in the index of the plan; and
- Approved labeling system to identify contents on all containers on site.

3.1.3 Site Restoration and Waste Handling

After drilling activities are complete, each sampling location will be restored as closely to its original condition as possible. Soils generated during site investigation activities at FTA 2 and Area A may potentially contain a listed hazardous waste. These soils will be visually examined and field screened for VOCs with an organic vapor meter (OVM). If soils are not visually contaminated and have a headspace reading of less than 5 parts per million, volume per volume (ppmv), then the soil will be contained and staged at assigned accumulation points for appropriate disposal as nonhazardous waste. Otherwise, the soil will be containerized, and transported to a central staging area pending receipt of groundwater quality data from the installed

monitoring points or wells. If the groundwater samples do not contain VOC concentrations in excess of the toxicity characteristics leaching procedure (TCLP) criteria, then the soils will be disposed of with nonhazardous soils as directed by Base personnel. If the VOC concentrations in groundwater exceed TCLP criteria; then the soils will be sampled for analysis of RCRA hazardous waste characteristics (ignitability, corrosivity, reactivity, and toxicity). If applicable hazardous waste criteria are exceeded, then the soil will be disposed of as a hazardous waste at an appropriate offsite facility by USACE.

Groundwater removed from monitoring wells during development or purging, used for decontamination, or generated from drilling activities, will be temporarily contained and transported to assigned accumulation points. Water will be contained in large capacity storage tanks to allow settling of solids, if necessary. The water will then be disposed of by Parsons ES or the USACE to the Base GWTP. If the water cannot be accepted by the Base GWTP, the water will be disposed of by the Base using another acceptable means (e.g., the Base IWTP, or a licensed contractor will transport the wastewater to a treatment and/or disposal facility).

Precautions will be taken to prevent spills of hazardous material. In the event of a spill, the Base POC will be notified immediately. Spill response will be in accordance with Title 40 of the Code of Federal Regulations, Part 300 (40 CFR 300) and applicable state regulations.

3.2 MONITORING POINT/WELL DRILLING, SOIL SAMPLING, AND INSTALLATION

To further characterize site hydrogeologic conditions and groundwater chemistry, an estimated total of up to 17 groundwater monitoring points or wells, and 5 optional monitoring points or wells, will be installed within and adjacent to FTA 2 and Area A CAH or BTEX plumes to supplement previously installed site monitoring wells. Small-diameter [0.05-inch inside diameter (ID), polyvinyl chloride (PVC)] monitoring

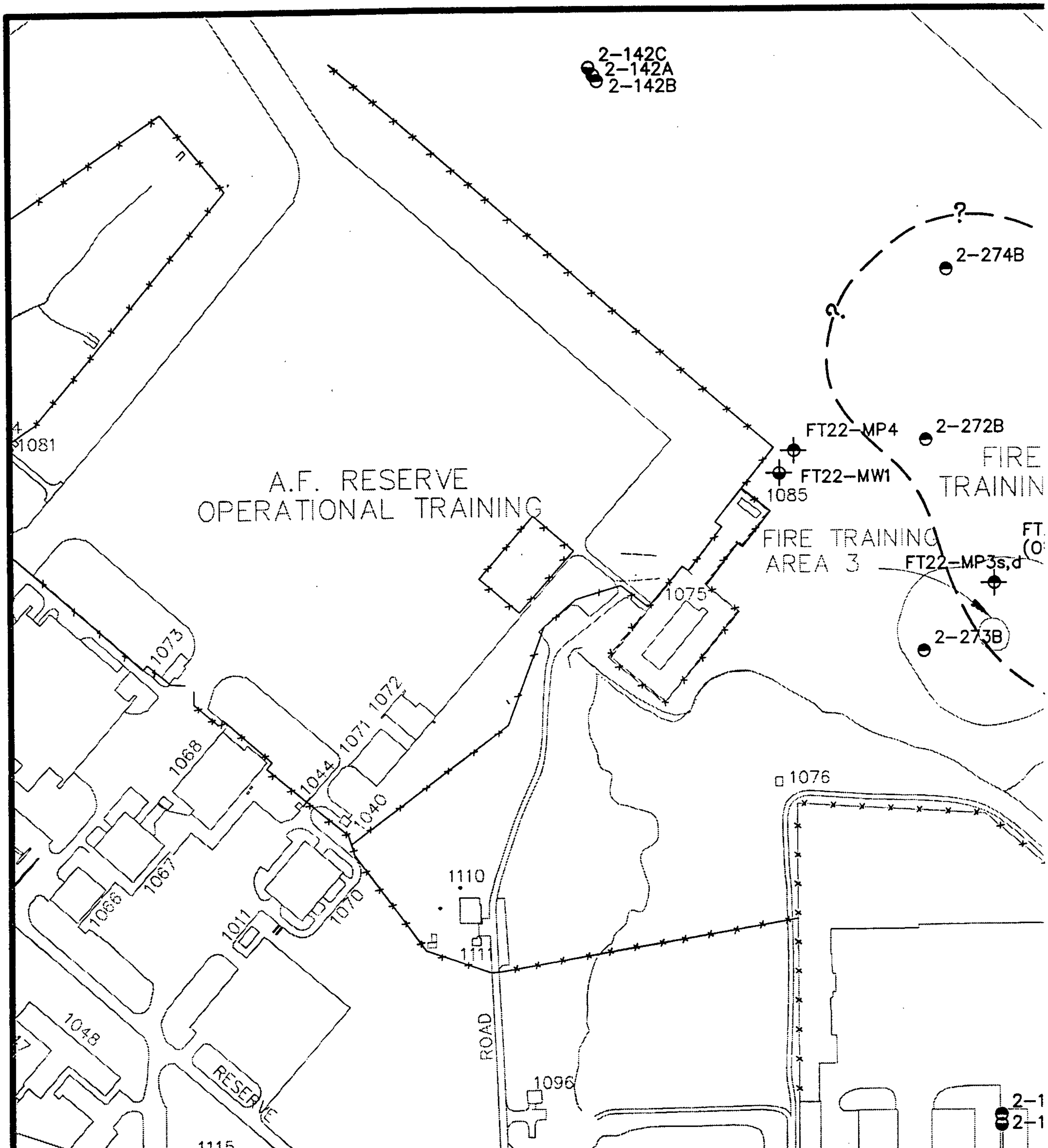
points will be installed using a Geoprobe® or hollow-stem auger (HSA) in the USZ where the groundwater is sufficiently near the ground surface (within approximately 25 feet) to allow use of a peristaltic pump to perform purging and sampling activities. Two-inch inside-diameter (ID) monitoring points will be installed using a HSA in the USZ where the depth to groundwater is deeper than approximately 25 feet. Double-cased, two or four-inch inside-diameter (ID) monitoring wells will be installed in the LSZ using wet-rotary drilling.

Monitoring points and wells will be installed by the USACE. The following sections describe the proposed monitoring point and well locations and completion intervals. Monitoring point and well installation, development, and decontamination will be performed in accordance with Tinker AFB well installation standards (Appendix D), as applicable. The following sections summarize the general monitoring point and well installation and development, as well as equipment decontamination, procedures.

3.2.1 Monitoring Point and Well Locations and Completion Intervals

3.2.1.1 FTA 2 Monitoring Point and Well Locations and Completion Intervals

The locations of the proposed 7 groundwater monitoring points/wells, and 1 optional monitoring points for FTA 2 are identified on Figure 3.1. These locations were determined following a review of data gathered during previous site activities (IT, 1994 and Tinker AFB). Monitoring point/well locations were selected to provide hydrogeologic data necessary for successful implementation of a site-specific contaminant fate and transport model and to monitor potential chlorinated solvent migration from the site. Monitoring point/well locations were also selected to provide additional data on natural attenuation processes in the CAH plume. The 7 proposed locations shown on Figure 3.1 may be modified in the field as a result of conditions encountered in the field and acquired field data. The wells will be placed with the intent of verifying the downgradient plume extent and for collecting additional data



LEGEND

2-142B	UPPER SATURATED ZONE MONITORING WELL LOCATION AND ID NUMBER	FT22-MW1	PROPOSED MONITORII LOWER SATURATED Z
2-142A	LOWER SATURATED ZONE MONITORING WELL LOCATION AND ID NUMBER	s,d	SHALLOW AND DEEP POINT/WELL PAIR
FT22-MP1	PROPOSED MONITORING POINT/WELL LOCATION/ UPPER SATURATED ZONE		DIRECTION OF USZ G
			APPROXIMATE EXTEN CAH PLUME

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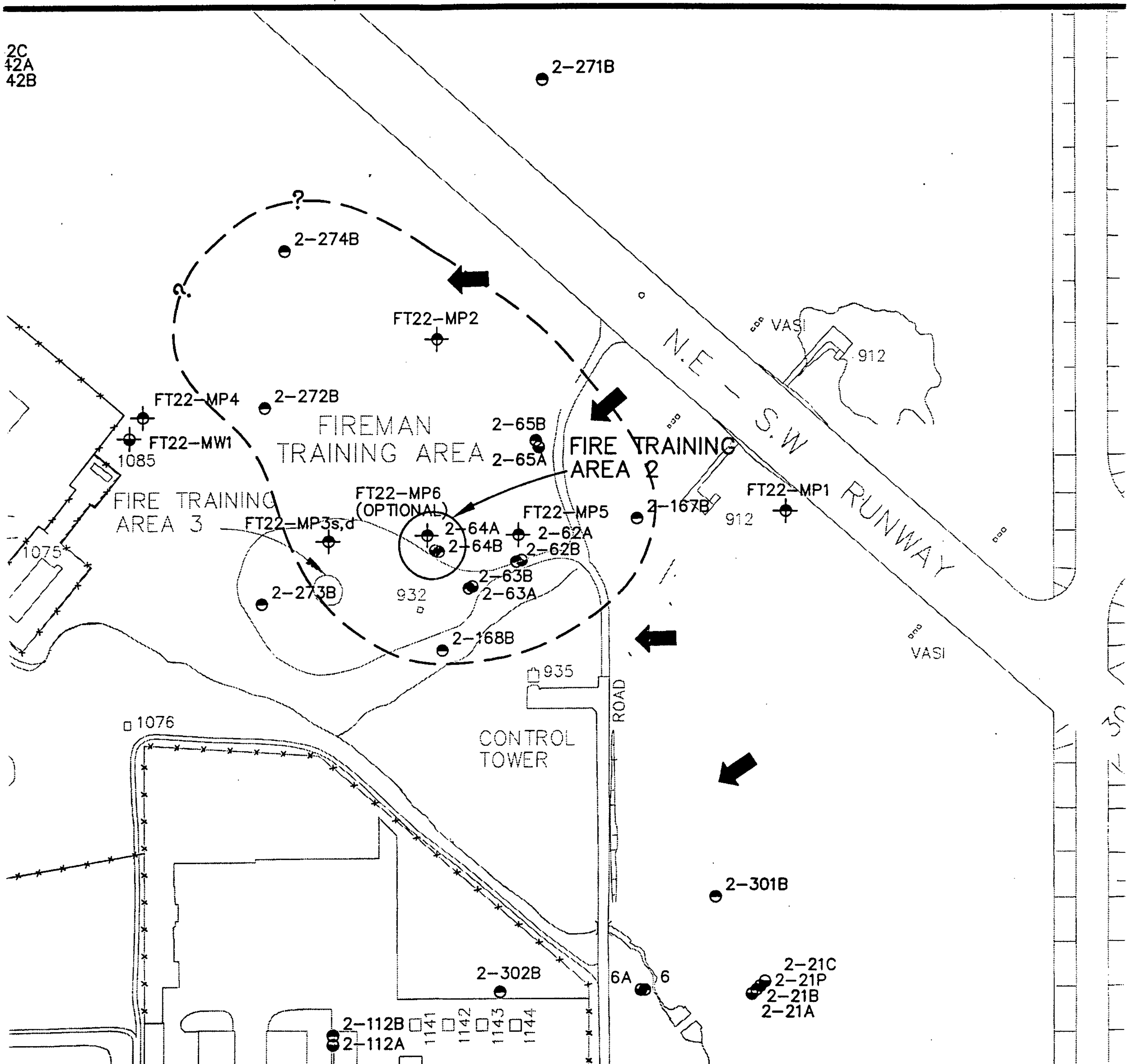
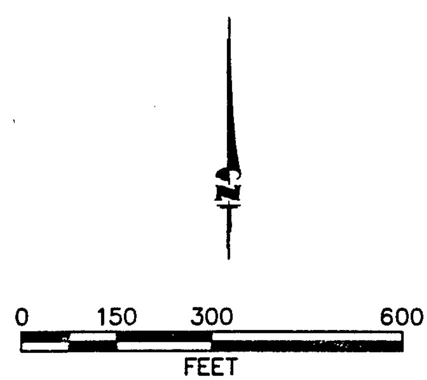


D

FT22-MW1	PROPOSED MONITORING WELL LOCATION/ LOWER SATURATED ZONE
s,d	SHALLOW AND DEEP USZ MONITORING POINT/WELL PAIR
/	DIRECTION OF USZ GROUNDWATER FLOW
	APPROXIMATE EXTENT OF USZ CAH PLUME



2

F
E

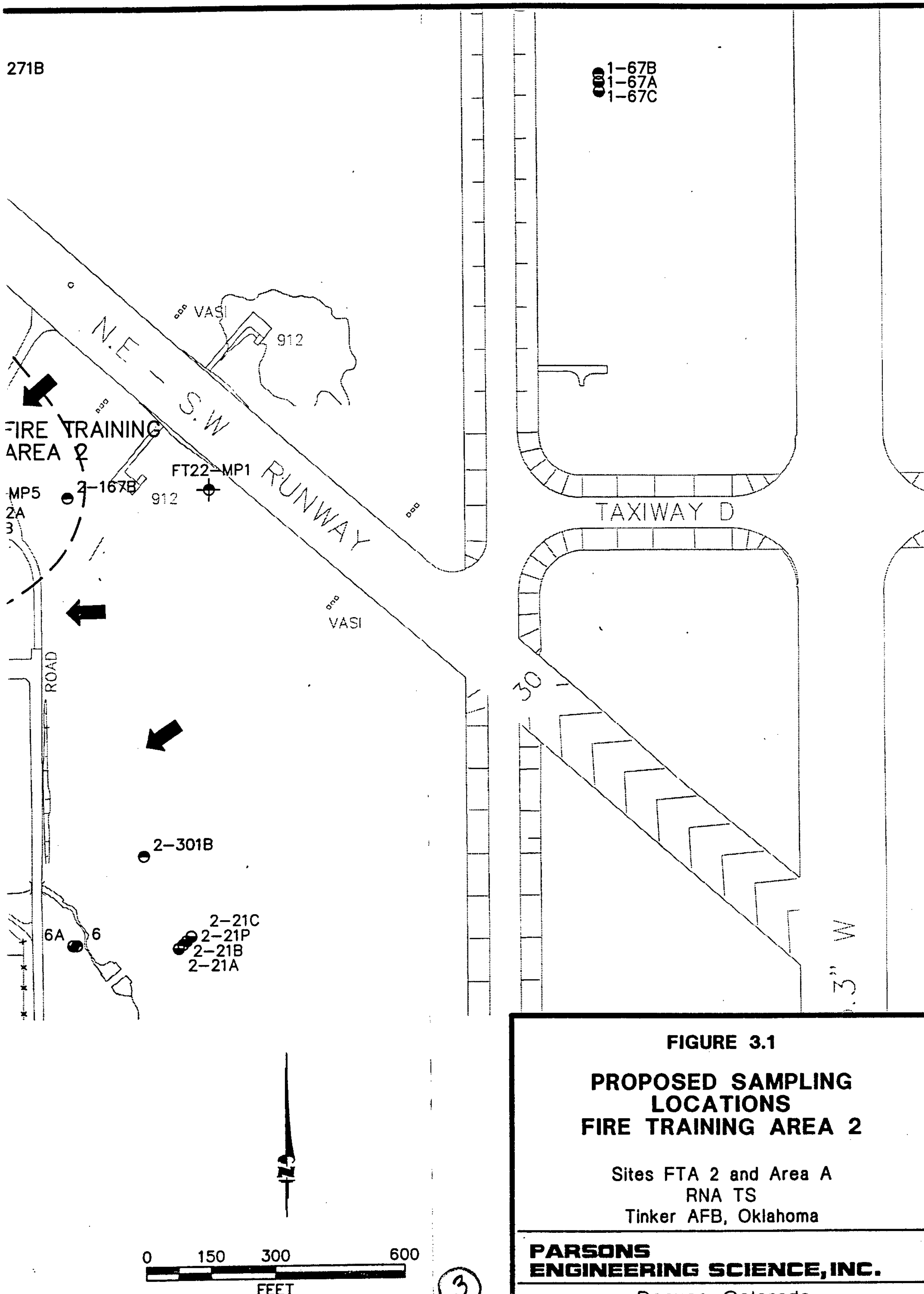


FIGURE 3.1

PROPOSED SAMPLING LOCATIONS FIRE TRAINING AREA 2

Sites FTA 2 and Area A
RNA TS
Tinker AFB, Oklahoma

PARSONS ENGINEERING SCIENCE, INC.

Denver, Colorado

③

within, up-, and cross-gradient from the plume. The rationale for the location of each of the proposed monitoring points/wells is provided in Table 3.2.

Monitoring points/wells may be installed singly, or in clusters of two points/well pairs. Single monitoring points/wells will be screened in the proper interval to detect maximum contaminant concentrations on the basis of data provided by IT (1994). Estimated screen intervals for all of the proposed monitoring points and wells are indicated in Table 3.2. These intervals may be altered in the field based on actual conditions encountered. Monitoring point/well clusters will be installed at locations where it is desirable to assess variations in groundwater chemistry with depth in the USZ, and to assess groundwater chemistry in the LSZ.

3.2.1.2 Area A Monitoring Well Locations and Completion Intervals

The locations of 10 proposed groundwater monitoring points/wells, and 4 optional monitoring points are identified on Figure 3.2. These locations were determined following a review of data gathered during previous site activities (IT, 1996). Monitoring point/well locations were selected to provide hydrogeologic data necessary for successful implementation of a site-specific contaminant fate and transport model and to monitor potential BTEX and CAH migration from the site. Monitoring well locations were also selected to provide additional data on natural attenuation processes in the BTEX and CAH plumes. The 10 proposed locations shown on Figure 3.2 may be modified in the field as a result of conditions encountered in the field and acquired field data. The wells will be placed with the intent of verifying the downgradient plume extent and for collecting additional data within, and up- and cross-gradient from the plumes. The rationale for the location of each of the proposed monitoring points/wells is provided in Table 3.3.

Monitoring wells may be installed singly, or in clusters of up to three points or wells. Single monitoring points will be screened in the proper interval to detect

TABLE 3.2
PROPOSED MONITORING WELL SUMMARY, FTA 2
SITES FTA 2 AND AREA A
RNA TS
TINKER AFB, OKLAHOMA

Well/Borehole Identification	Well I.D.[a] (Inches)	Total Depth (Feet bgs)[b]	Drilling Method[c]	Screened Interval (Feet bgs)	Estimated Depth to Water (Feet bgs)	Screened Aquifer Zone[d]	Plume Location	Rationale
New Monitoring Points (USZ)								
FT22-MP1	0.5 - 2.0	38'	Geoprobe/HSA	27-37'	16'	1st USZ Sand	Upgradient	Determine upgradient groundwater geochemistry, and CAH concentrations from potential offsite sources.
FT22-MP2	0.5 - 2.0	40'	Geoprobe/HSA	34-39'	13'	Base USZ	Lateral	Define USZ CAH plume extent to the south and collect cross-gradient geochemical data.
FT22-MP3	0.5 - 2.0	43'	Geoprobe/HSA	37-42'	16'	Base USZ	Lateral	Define USZ CAH plume to the north and apparent secondary CAH plume near well 2-274B. Collect cross-gradient geochemical data.
FT22-MP4s	0.5 - 2.0	26'	Geoprobe/HSA	20-25'	14'	1st USZ Sand	Plume Axis	Determine geochemistry and CAH concentrations in groundwater along plume axis.
FT22-MP4d	0.5 - 2.0	45'	Geoprobe/HSA	39-44'	14'	Base USZ	Plume Axis	Determine geochemistry and CAH concentrations in groundwater along plume axis.
FT22-MP5	0.5 - 2.0	45'	Geoprobe/HSA	39-44'	15'	Base USZ	Plume Axis/ Downgradient	Determine geochemistry and CAH concentrations in groundwater downgradient along the plume axis.
FT22-MP6 (optional)	0.5 - 2.0	45'	Geoprobe/HSA	39-44'	14'	Base USZ	Plume Axis	Pair well with 2-64B in the USZ to determine vertical groundwater geochemistry and CAH distributions.
FT22-MP7 (optional)	0.5 - 2.0	40'	Geoprobe/HSA	34-39'	14'	Base USZ	Plume Axis	Pair well with 2-62B in the USZ to determine vertical groundwater geochemistry and CAH distributions.
New Monitoring Wells (LSZ)								
FT22-MW1	2.0 - 4.0	83'	Wet Rotary	79-80'	55-60'	1st LSZ Sand	Downgradient	Determine if the USZ CAH plume infiltrates the LSZ in a downgradient direction.

[a] I.D. indicates well casing inside diameter.
[b] feet bgs indicates elevation in feet below ground surface.
[c] Drilling methods include Geoprobe direct-push, hollow-stem auger (HSA), and wet-rotary drilling techniques.
[d] Screened intervals include the upper-saturated zone (USZ) and the lower-saturated zone (LSZ).

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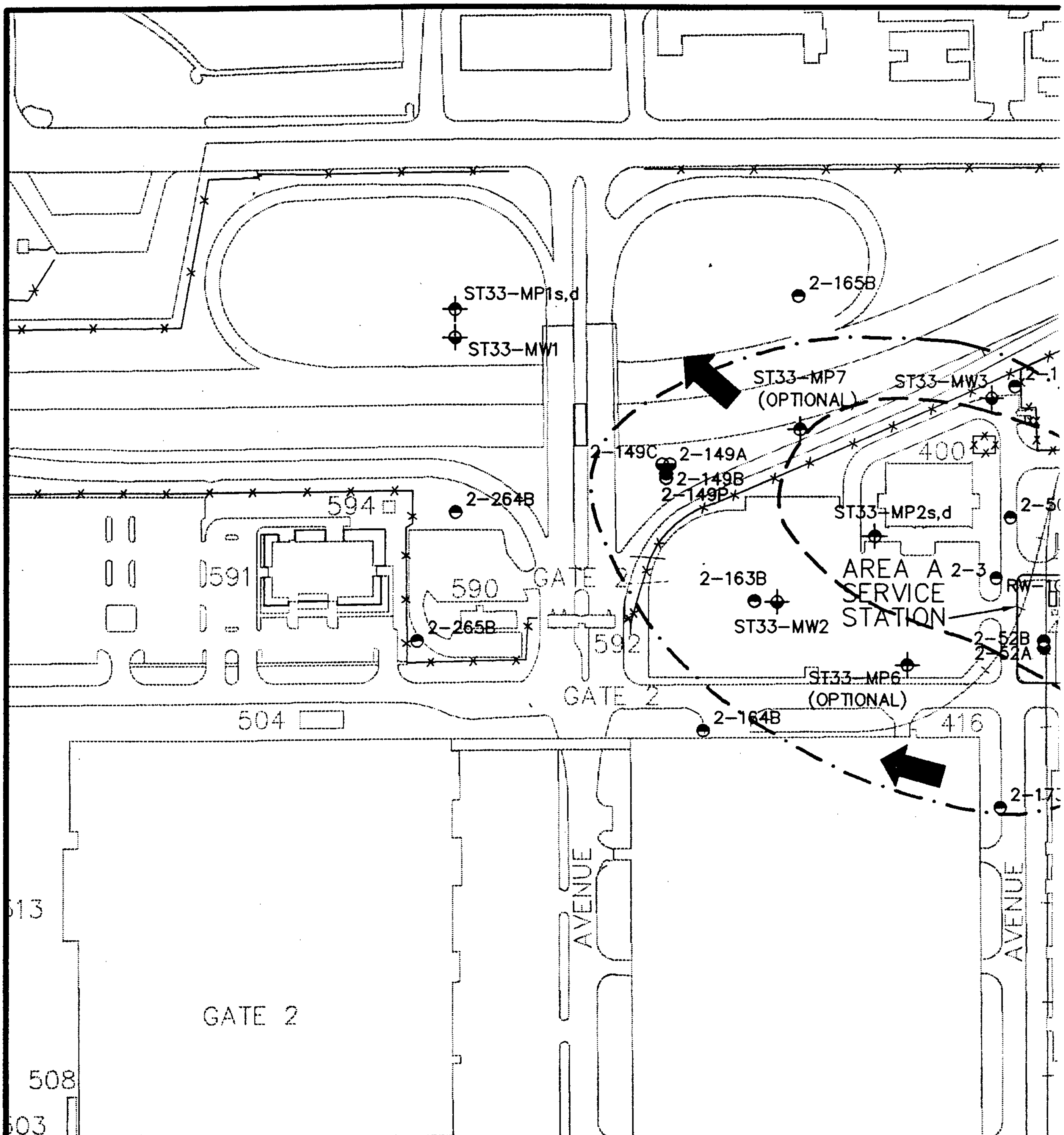
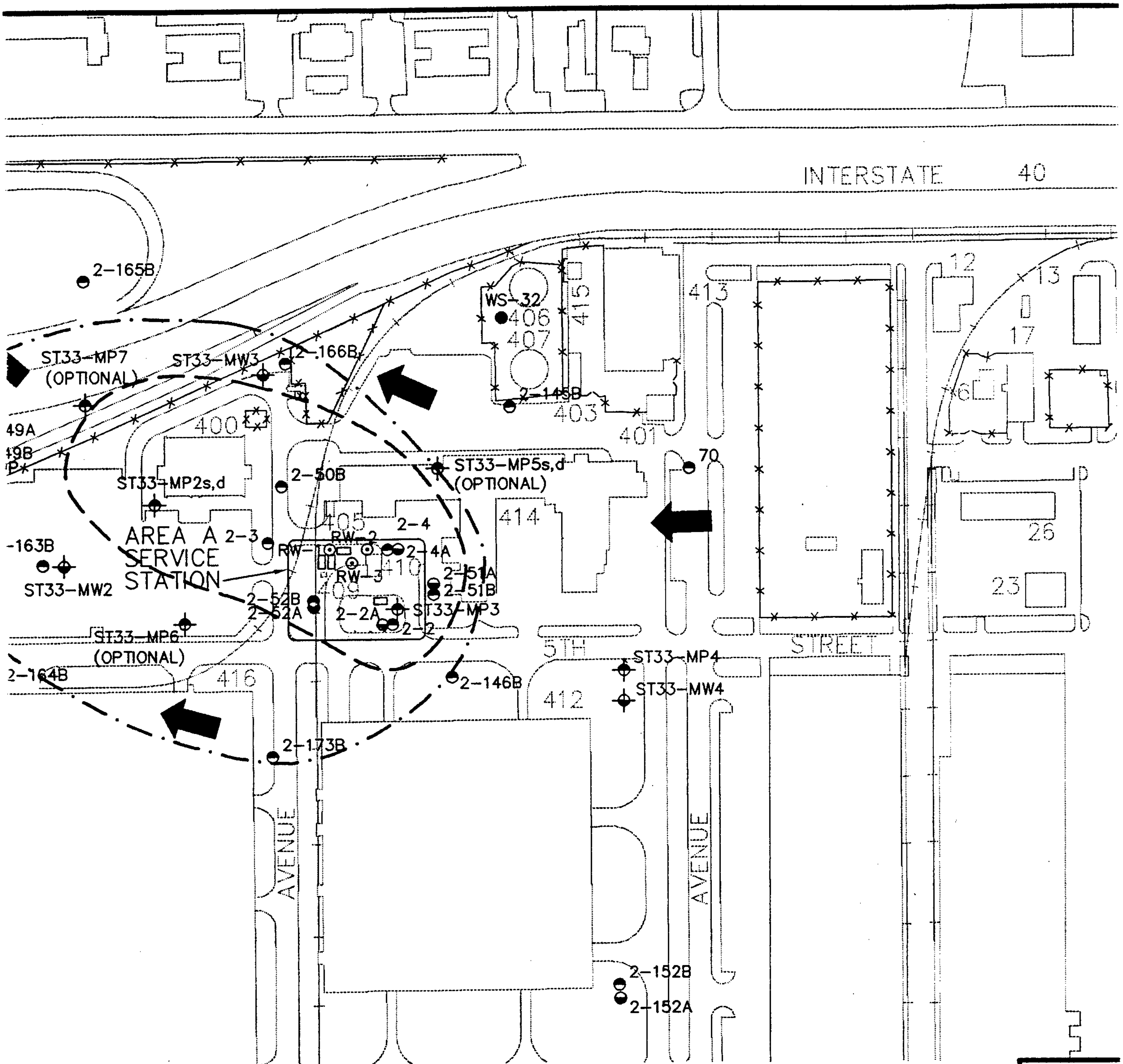


LEGEND

ST33-MP1	PROPOSED MONITORING POINT LOCATION/ UPPER SATURATED ZONE	2-165B	UPPER SATURATED ZONE MO LOCATION AND ID NUMBER
ST33-MW1	PROPOSED MONITORING WELL LOCATION/ LOWER SATURATED ZONE	2-2A	LOWER SATURATED ZONE MO LOCATION AND ID NUMBER
s,d	SHALLOW AND DEEP USZ MONITORING POINT PAIR		DIRECTION OF USZ GROUNDWATE
WS-32	WATER SUPPLY WELL		APPROXIMATE EXTEND OF BTEX IN USZ GROUNDWATER
			APPROXIMATE EXTEND OF CAHs IN USZ GROUNDWATER

1



UPPER SATURATED ZONE MONITORING WELL LOCATION AND ID NUMBER

LOWER SATURATED ZONE MONITORING WELL LOCATION AND ID NUMBER

DIRECTION OF USZ GROUNDWATER FLOW

APPROXIMATE EXTEND OF BTEX IN USZ GROUNDWATER

APPROXIMATE EXTEND OF CAHs IN USZ GROUNDWATER

0 100 200 400
FEET

2

PARS
ENGIN

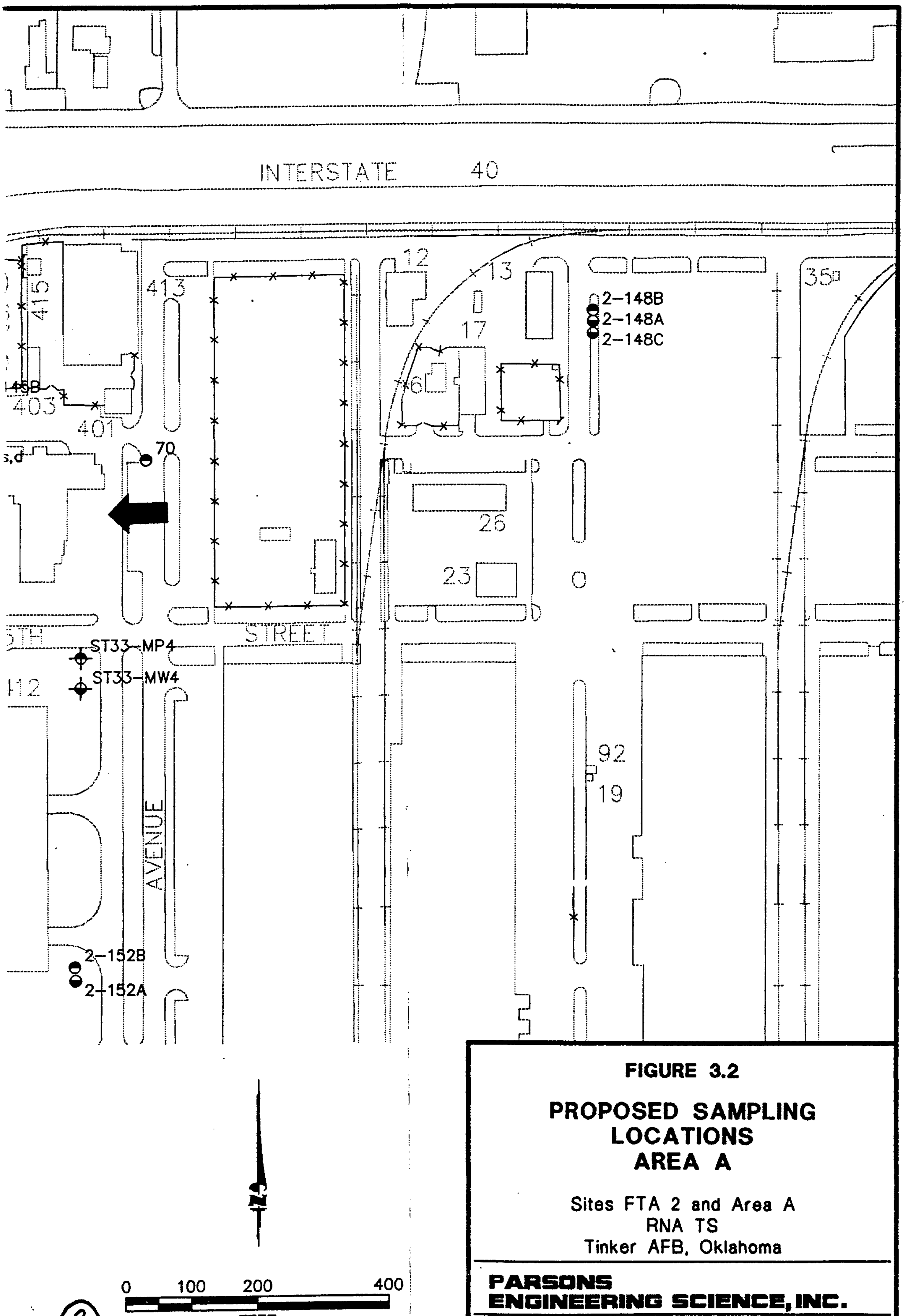


FIGURE 3.2

PROPOSED SAMPLING LOCATIONS AREA A

Sites FTA 2 and Area A
RNA TS
Tinker AFB, Oklahoma

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TABLE 3.3
PROPOSED MONITORING WELL SUMMARY, AREA A
SITES FTA 2 AND AREA A
RNA TS
TINKER AFB, OKLAHOMA

Well/Borehole Identification	Well I.D.[a] (Inches)	Total Depth (Feet bgs)[b]	Drilling Method[c]	Screened Interval (Feet bgs)	Estimated Depth to Water (Feet bgs)	Screened Aquifer Zone[d]	Plume Location	Rationale
New Monitoring Points (USZ)								
ST33-MP1s	0.5 - 2.0	25'	Geoprobe/HSA	19-24'	20'	Water Table	Downgradient	Determine downgradient groundwater geochemistry and downgradient extent of USZ BTEX and CAH plumes.
ST33-MP1d	0.5 - 2.0	31'	Geoprobe/HSA	30-35'	20'	Base USZ	Downgradient	Pair point with MP1s in the USZ to determine vertical groundwater geochemistry, BTEX, and CAH distributions.
ST33-MP2s	0.5 - 2.0	21'	Geoprobe/HSA	15-20'	16'	Water Table	Plume Axis	Determine groundwater geochemistry, BTEX, and CAH concentrations along the plume axis.
ST33-MP2d	0.5 - 2.0	37'	Geoprobe/HSA	31-36'	16'	Base USZ	Plume Axis	Pair point with MP2s in the USZ to determine vertical groundwater geochemistry, BTEX, and CAH distributions.
ST33-MP3	0.5 - 2.0	37'	Geoprobe/HSA	31-36'	13-15'	Base USZ	Plume Axis	Pair point with 2-2 in the USZ to determine vertical (base USZ) groundwater geochemistry, BTEX, and CAH distributions.
ST33-MP4	0.5 - 2.0	36'	Geoprobe/HSA	25-35'	10'	Mid USZ Sand	Upgradient	Determine upgradient groundwater geochemistry, and CAH concentrations from potential offsite sources.
ST33-MP5s (optional)	0.5 - 2.0	20'	Geoprobe/HSA	14-19'	15'	Water Table	Lateral	Determine cross-gradient groundwater geochemistry and lateral extent of USZ BTEX and CAH plumes.
ST33-MP5d (optional)	0.5 - 2.0	36'	Geoprobe/HSA	30-35'	15'	Base USZ	Lateral	Pair point with MP5s in the USZ to determine vertical groundwater geochemistry, BTEX, and CAH distributions.
ST33-MP6 (optional)	0.5 - 2.0	36'	Geoprobe/HSA	30-35'	13'	Base USZ	Lateral	Determine groundwater geochemistry, BTEX, and CAH concentrations lateral to USZ BTEX and CAH plumes.
ST33-MP7 (optional)	0.5 - 2.0	36'	Geoprobe/HSA	30-35'	10'	Base USZ	Lateral	Determine groundwater geochemistry, BTEX, and CAH concentrations lateral to USZ BTEX and CAH plumes.
New Monitoring Wells (LSZ)								
ST33-MW1	2.0 - 4.0	55'	Wet Rotary	42-52'	45'	1st LSZ Sand	Downgradient	Determine downgradient groundwater geochemistry and downgradient extent of LSZ CAH plume.
ST33-MW2	2.0 - 4.0	60'	Wet Rotary	47-57'	45'	1st LSZ Sand	Lateral	Determine cross-gradient groundwater geochemistry and CAH concentrations lateral to LSZ CAH plume.
ST33-MW3	2.0 - 4.0	75'	Wet Rotary	62-72'	45'	2nd LSZ Sand	Lateral	Determine cross-gradient groundwater geochemistry and CAH concentrations lateral to LSZ CAH plume.
ST33-MW4	2.0 - 4.0	73'	Wet Rotary	60-70'	45'	2nd LSZ Sand	Upgradient	Determine upgradient groundwater geochemistry, and CAH concentrations from potential offsite sources.

a/ I.D. indicates well casing inside-diameter.
b/ feet bgs indicates elevation in feet below ground surface.
c/ Drilling methods include Geoprobe direct-push, hollow-stem auger (HSA), and wet rotary drilling techniques.
d/ Screened intervals include the upper-saturated zone (USZ) and the lower-saturated zone (LSZ).

L:\TINKER\WORKPLAN\AREA-A\AOC-WELL.XLS

maximum contaminant concentrations on the basis of data provided by IT (1996). Estimated screen intervals for all of the proposed monitoring wells and points are indicated in Table 3.3. These intervals may be altered in the field based on actual conditions encountered. Monitoring point clusters will be installed at locations where it is desirable to assess variations in groundwater chemistry with depth in the USZ, and to assess groundwater chemistry in the LSZ.

3.2.2 Monitoring Point and Well Advancement and Installation Procedures

Monitoring points will be advanced using a truck-mounted Geoprobe® or a drilling rig equipped with 4.25-inch-ID HSAs in the USZ, and monitoring wells will be advanced using a wet-rotary drilling rig in the LSZ. USACE will be responsible for all drilling, sampling, development, drilling waste disposal, and completion activities. All drilling and completion activities will be performed in accordance with Tinker AFB well installation standards (Appendix D).

A USACE field scientist will be responsible for observing all monitoring point/well field investigation activities, maintaining a detailed descriptive log of all subsurface materials recovered during soil coring, photographing representative samples, and properly labeling and storing samples. During borehole advancement, soil samples for visual description will be collected at a frequency sufficient to identify the depths of significant stratigraphic contacts (e.g., contacts between fill material and alluvium, between alluvium and bedrock, and between bedrock stratigraphic units). Sampling intervals will be determined on the basis of Tinker AFB well installation requirements. Soil samples will be obtained using a Geoprobe® soil drive sampler, a split-spoon sampling device, a continuous California sampler, or another similar method judged to be acceptable by the USACE field scientist. An example geologic borehole log form is presented in Figure 3.3. The descriptive log will contain data items listed in the Tinker AFB well installation standard (Appendix D), including the following:

Sheet __ of __

GEOLOGIC BORING LOG

JOB NUMBER: ____________ CLIENT: ____________ DATE SPUD: ____________

BORING NUMBER: ____________ BORING DIA.: ____________ DATE CMPL: ____________

RIG TYPE: ____________ CONTRACTOR: ____________ ELEVATION: ____________

TEMPERATURE (°F): ____________ WEATHER: ____________ DATUM: ____________

LOCATION: ____________ DRLG MED: ____________ GEOLOGIST: ____________

COMMENTS: ____________

Depth (ft.)	Pro-file	USCS	Geologic Description	Sample Interval	Laboratory Sample Identification	Sample Type	PID ppmv	Remarks
1								
5								
10								
15								
20								
25								
30								

NOTES:

BGS - Below Ground Surface
NS - Not Sampled
TOC - Top of Casing
PID - Photoionization Detector
ppmv - Parts per Million, Volume per Volume

SS - Split Spoon Sample
G - Grab Sample
D - Drive Sample

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FIGURE 3.3

GEOLOGIC BORING LOG

Sites FTA 2 and Area A
RNA TS
Tinker AFB, Oklahoma

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- Sample interval (top and bottom depth);
- Sample recovery;
- Presence or absence of contamination [as indicated by photoionization detection (PID) readings];
- Lithologic description, including relative density, color, major textural constituents, minor constituents, relative moisture content, plasticity of fines, cohesiveness, grain size, structure or stratification, and any other significant observations; and
- Depths of lithologic contacts and/or significant textural changes measured and recorded to the nearest 0.1 foot.

Monitoring well installation and completion materials will be inspected by the field scientist and determined to be clean and acceptable prior to use. If not factory sealed, the well points, casing, and tubing will be cleaned prior to use with a high-pressure, steam/hot-water cleaner using approved water. Materials that cannot be cleaned to the satisfaction of the field scientist will not be used. The field scientist will verify and record the borehole depth, the lengths of all casing sections, and the depth to the top of all well completion materials placed in the annulus between the casing and the borehole wall. All lengths and depths will be measures to the nearest 0.1 foot. Specific materials to be used for construction of USZ and LSZ wells are described in the following subsections.

3.2.2.1 USZ Monitoring Points/Wells

If subsurface conditions permit, monitoring points will be constructed of 0.75-inch outside-diameter (OD)/0.5-inch-ID PVC casing and well screen to provide additional water level and water quality data. Approximately 5 feet of factory-slotted screen will be installed for each shallow monitoring point. Effective installation of the shallow

monitoring points requires that the boreholes remain temporarily open upon completion of Geoprobe® penetration. Shallow 0.5-inch-ID PVC monitoring points will be installed by punching and sampling a borehole with the Geoprobe®. Upon removing the rods, the borehole depth will be measured to determine if the hole remains open. If the borehole is open, the 0.5-inch-ID PVC casing and screen will be placed at the appropriate depths. The annular space around the screen will be filled with sand filter pack, and the annulus around the casing will be filled with grout or bentonite. Monitoring point construction details will be noted on a Monitoring Point Construction diagram (Figure 3.4). This information will become part of the permanent field record for the site.

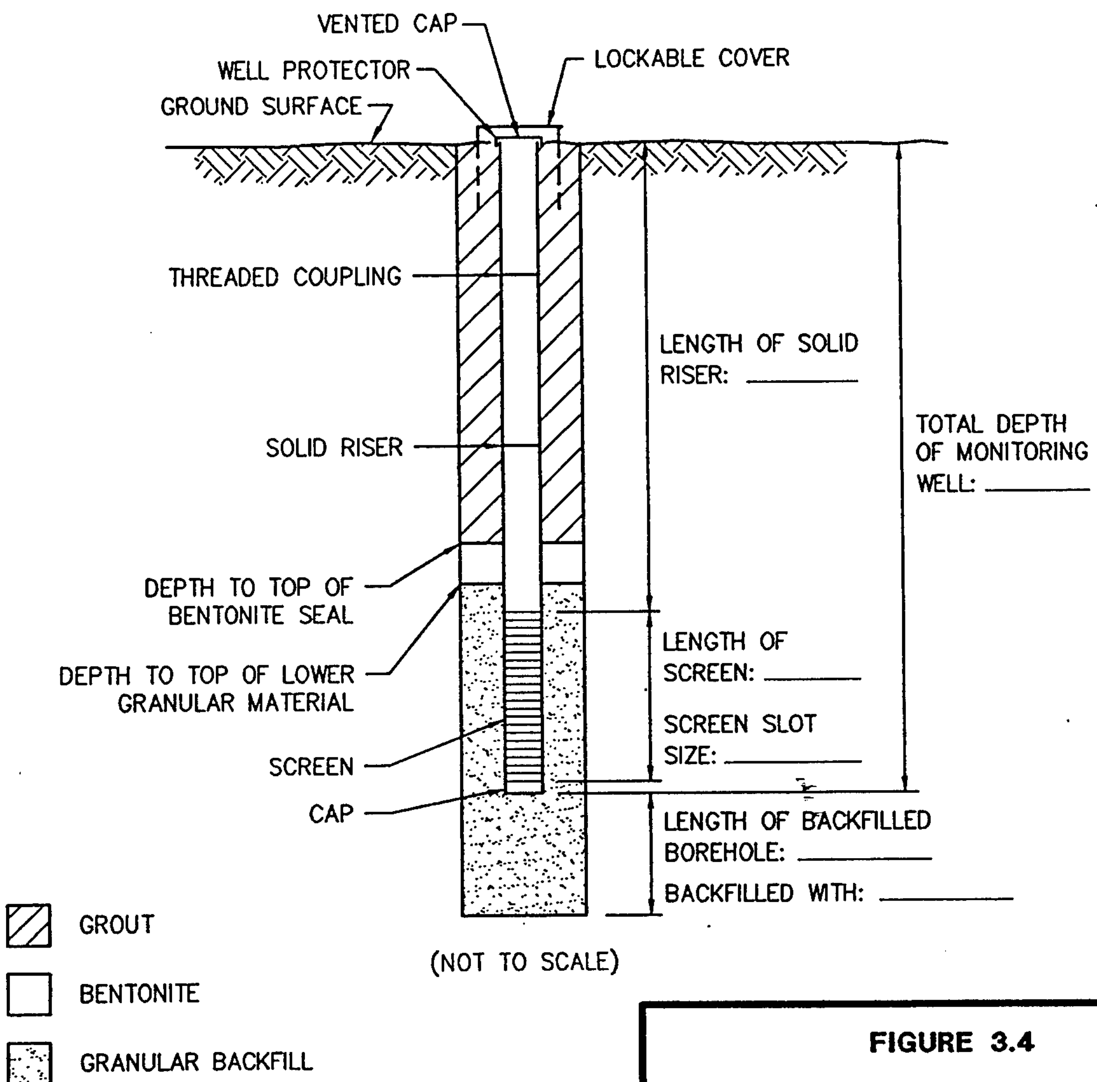
Monitoring point screens will be constructed of flush-threaded, Schedule 40 PVC with an ID of 0.5 inch. The screens will be factory slotted with 0.01-inch openings. Placement depth for monitoring point screens is described in Tables 3.2 and 3.3, along with the rationale for the selection of this depth. Blank monitoring point casing will be constructed of Schedule 40 PVC with an ID of 0.5 inch. All monitoring point casing sections will be flush-threaded; joints will not be glued. The casing at each monitoring point will be fitted with a bottom cap and a top cap constructed of PVC. If 0.5-inch PVC monitoring points cannot be installed, or the depth to water is greater than 25 feet, 2.0-inch ID PVC monitoring points be installed using a HSA drill rig. Screen slot size for 2.0-inch PVC monitoring points will be 0.10 inch, with a screen length of 10 feet.

3.2.2.2 LSZ Monitoring Wells

Double-cased monitoring well construction details will be noted on a Monitoring Well Construction diagram (Figure 3.5). LSZ monitoring wells will be drilled, sampled, and installed by the USACE, under supervision of a qualified USACE field scientist. LSZ monitoring well installation, development, and decontamination will be performed in accordance with Tinker AFB well installation standards (Appendix D).

SINGLE-CASED MONITORING POINT INSTALLATION RECORD

JOB NAME TINKER AIR FORCE BASE ______ WELL NUMBER ______
JOB NUMBER 729691 ______ INSTALLATION DATE ______ LOCATION ______
DATUM ELEVATION ______ GROUND SURFACE ELEVATION ______
DATUM FOR WATER LEVEL MEASUREMENT ______
SCREEN DIAMETER & MATERIAL ______ SLOT SIZE ______
RISER DIAMETER & MATERIAL ______ BOREHOLE DIAMETER ______
GRANULAR BACKFILL MATERIAL ______ ES REPRESENTATIVE ______
DRILLING METHOD GEOPROBE/HOLLOW STEM AUGER ______ DRILLING CONTRACTOR ______



(NOT TO SCALE)

STABILIZED WATER LEVEL ______ FEET
BELOW DATUM.
MEASURED ON ______

FIGURE 3.4

SINGLE-CASED MONITORING POINT INSTALLATION RECORD

Sites FTA 2 and Area A
RNA TS
Tinker AFB, Oklahoma

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DOUBLE-CASED MONITORING WELL INSTALLATION RECORD

JOB NAME TINKER AIR FORCE BASE ____ WELL NUMBER ____

JOB NUMBER 729691 ____ INSTALLATION DATE ____ LOCATION ____

DATUM ELEVATION ____ GROUND SURFACE ELEVATION ____

DATUM FOR WATER LEVEL MEASUREMENT ____

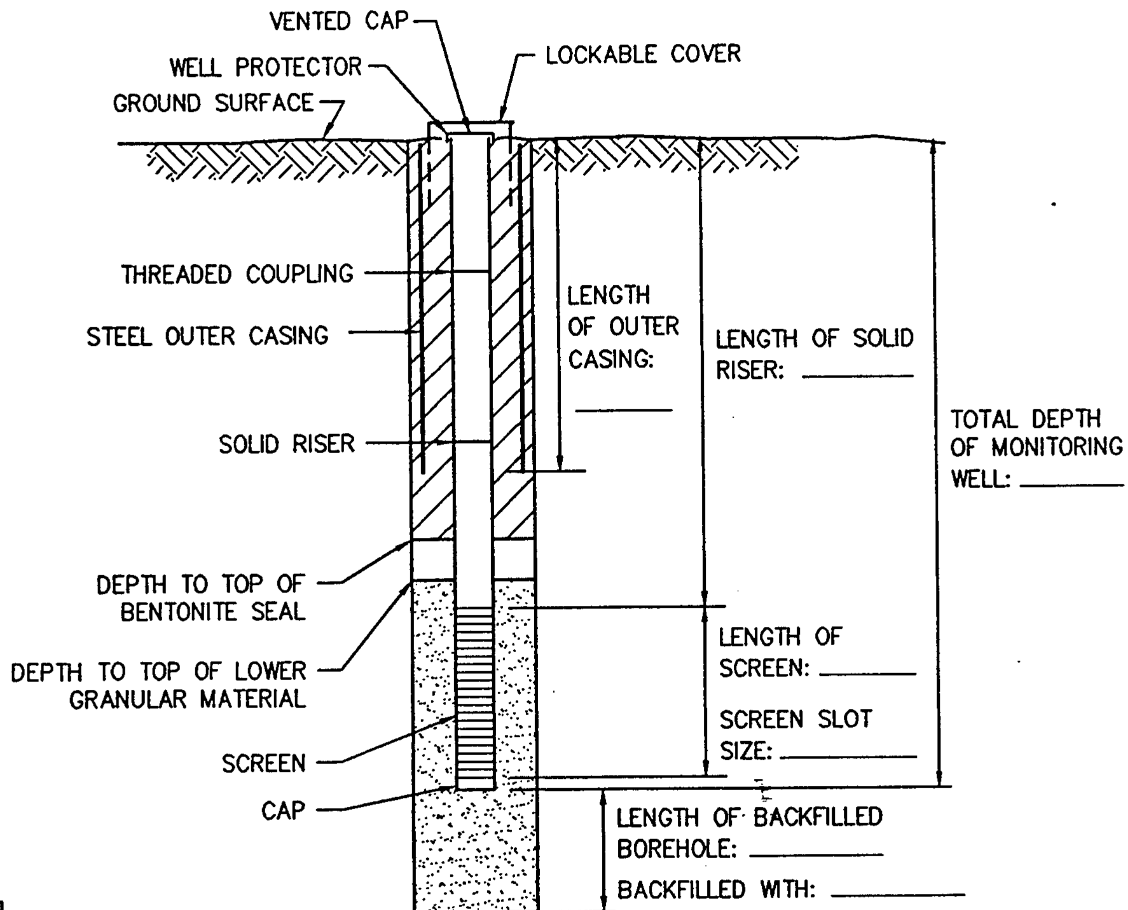
CASING DIAMETER & MATERIAL ____ BOREHOLE DIAMETER ____

SCREEN DIAMETER & MATERIAL ____ SLOT SIZE ____

RISER DIAMETER & MATERIAL ____ BOREHOLE DIAMETER ____

GRANULAR BACKFILL MATERIAL ____ ES REPRESENTATIVE ____

DRILLING METHOD WET-ROTARY ____ DRILLING CONTRACTOR ____



(NOT TO SCALE)

GROUT

BENTONITE

GRANULAR BACKFILL

STABILIZED WATER LEVEL ____ FEET BELOW DATUM.
MEASURED ON ____

FIGURE 3.5

DOUBLE-CASED MONITORING WELL INSTALLATION RECORD

Sites FTA 2 and Area A
RNA TS
Tinker AFB, Oklahoma

PARSONS ENGINEERING SCIENCE, INC.

Denver, Colorado

LSZ monitoring wells will be double-cased to the top of the USZ/LSZ aquitard. The outer casing will consist of a stainless steel casing keyed into the top of the hard silt/clay USZ aquitard. The casing ID will be a minimum of 8.5 inches in order to accommodate a borehole for installation of a 2- or 4-inch well surrounded by a minimum 2-inch annulus. The LSZ wells will be completed with 2- or 4-inch ID PVC screen and riser. Screens will be 15 feet long with a 0.10-inch slot size.

3.2.3 Collection of Soil Samples for Field Screening and Laboratory Analysis During Monitoring Well/Point Drilling

Soil samples will be collected at 5-foot intervals throughout the vadose zone during drilling of monitoring point/wells located in or near potential contamination source areas (Figures 3.1 and 3.2). A portion of each sample will be used to measure the total ionizable VOC concentration in soil headspace using a PID. Each headspace screening sample will be placed in a clean, sealed plastic bag or mason jar and allowed to equilibrate to the ambient temperature for at least 15 minutes. The PID probe will then be inserted into the bag or jar, and the maximum reading will be recorded in the field records. If headspace readings significantly above background readings are obtained, indicating the presence of vadose zone contamination, then the sample may be submitted to a laboratory for analysis of VOCs using the method specified in Table 3.1. Each laboratory soil sample will be placed in an analyte-appropriate sample container and hand-delivered to the USEPA field laboratory personnel for analysis. If USEPA personnel have not mobilized to the site, then the samples will be shipped on ice to the NRMRL via overnight courier

Soil samples for TOC analysis will also be collected from selected monitoring well/point boreholes located in uncontaminated or minimally contaminated areas cross-gradient or downgradient from the CAH plume. One sample for TOC analysis will be collected from each major lithologic unit encountered in the saturated zone during

advancement of monitoring point/wells from a minimum of one upgradient location at each site.

3.2.4 Equipment Decontamination During Drilling and Soil Sampling Activities

Prior to arriving at the site, and between each sampling location, probe rods, tips, sleeves, pushrods, augers, drill rods, drill bits, samplers, tools, and other downhole equipment will be decontaminated using a high-pressure, steam/hot water wash. Only potable water will be used for decontamination.

When collecting soil samples for laboratory analysis of VOCs, the sampling device will be disassembled and decontaminated with Alconox® and potable water between each soil sample. Sampling barrels will then be rinsed with deionized water and a solvent (methanol or isopropanol), air-dried, and reassembled with new liners, if applicable. Between uses, the sampling equipment will be wrapped in clean plastic or foil to prevent contamination. Prior to collection of samples for TOC analysis, the sampling device will be rinsed with potable water and scrubbed with a stiff brush, as necessary, to remove soil particles from previous sampling intervals.

All rinseate will be collected for transportation and proper disposal with decontamination and development waters (Section 3.1.3). Alternate methods of rinseate disposal will be considered by the Parsons ES or USACE field scientist as recommended by Base personnel. Precautions will be taken to minimize any impact to the surrounding area that might result from decontamination operations.

3.2.5 Monitoring Point Development and Records

The newly installed monitoring points and wells will be developed prior to sampling to remove fine sediments and introduced fluids from the portion of the formation adjacent to the screened interval. Development of 0.5-inch ID PVC monitoring points will be accomplished using a peristaltic pump provided by USEPA NRMRL or Parsons

ES. Development of larger diameter monitoring points/wells will be accomplished using an electric submersible pump and, if necessary to obtain acceptable water clarity, a surging device. Monitoring point development will occur a minimum of 24 hours prior to sampling, and monitoring well development will occur a minimum of 72 hours prior to sampling.

Development will continue until a minimum of 5 times the standing water volume in the monitoring point/well (to include the well screen and casing plus saturated annulus, assuming 30-percent porosity) have been removed, and the water pH, temperature, and specific conductance have stabilized. Monitoring wells installed using wet-rotary drilling methods will develop an additional 5 times the measured amount of total fluids lost while drilling. If the development water is still turbid after removal of the minimum number of casing volumes, development will continue until the water becomes clear or the turbidity of the water produced has been stable after the removal of several additional casing volumes. In low-yield wells that go dry during development, development activity will be staged over a period of time to allow water to refill the well bore. In the event that the minimum number of casing volumes cannot be removed, the water volume recovered and the deficiency will be noted in the development records.

A development record will be maintained for each monitoring point and well. The development record will be completed in the field by the field scientist. Figure 3.6 is an example of a development record used for similar well installations. Development records will include at a minimum:

- Monitoring point/well number;
- Date and time of development;
- Development method;

Job Number: 729691.34020
Location: Tinker AFB FTA 2 / Area A
Well/Point ID: ________

Job Name: AFCEE-RNA
Developed by: ________ Date: ________
Measurement Datum ________

Pre-Development Information

Time (Start): ________

Water Level: ________ Total Depth of Well: ________

Initial Water Characteristics

Color ________ Clear Slightly Cloudy Cloudy
Odor: None Weak Moderate Strong
Any Films or Immiscible Material ________
pH ________ Temperature(°C) ________
Specific Conductance(μS/cm) ________

Interim Water Characteristics

Time: ________

Gallons Removed ________

pH ________

Temperature (°C) ________

Specific Conductance (μS/cm) ________

Post-Development Information

Time (Finish): ________

Water Level: ________ Total Depth of Well: ________

Gallons Removed: ________

Water Characteristics

Color ________ Clear Slightly Cloudy Cloudy
Odor: None Weak Moderate Strong
Any Films or Immiscible Material ________
pH ________ Temperature(°C) ________
Specific Conductance(μS/cm) ________

Comments:

FIGURE 3.6

MONITORING WELL DEVELOPMENT RECORD

Sites FTA 2 and Area A
RNA TS
Tinker AFB, Oklahoma

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- Monitoring point/well depth;

- Volume of water produced;

- Description of water produced;

- Post-development water level and monitoring point depth; and

- Field analytical measurements, including pH and specific conductivity.

Development waters will be collected and held for proper disposal to the Base GWTP. Alternate methods of water disposal will be considered by the USACE field scientist as recommended by Base personnel.

3.2.6 Datum Survey

The horizontal location of all soil sampling locations relative to established Base coordinates will be measured by a surveyor. Horizontal coordinates will be measured to the nearest 0.5 foot using a State Plane Lambert Coordinate System. Coordinates shall be reported in feet or meters using the 1983 North American Datum, Oklahoma North Zone; and in feet using the 1927 North American Datum, Oklahoma North Zone. The elevation of the ground surface and the top of well casings will also be measured to the nearest 0.01 foot using the NGVD of 1929.

3.3 GROUNDWATER SAMPLING PROCEDURES

This section describes the procedures for collection of groundwater quality samples. Groundwater samples will be collected from selected previously installed monitoring wells, and from all newly installed groundwater monitoring wells. Figures 3.1 and 3.2 show the locations of monitoring wells from which groundwater samples will be collected at FTA 2 and Area A, respectively. In order to maintain a high degree of QC during this sampling event, the procedures described in the following sections will be followed.

3.3.1 Groundwater Sampling Strategy

Groundwater samples will be collected from previously installed monitoring wells and from monitoring points/wells installed during this project (Figures 3.1 and 3.2). At FTA 2, the existing wells to be sampled will include 2-62B, 2-63B, 2-64B, 2-65B, 2-167B, 2-168B, 2-271B, 2-272-B, 2-273B, and 2-274B in the USZ; and 2-62A, 2-63A, 2-64A, and 2-65A in the LSZ. At Area A, the existing wells to be sampled will include 2-2, 2-3, 2-4, 2-50B, 2-51B, 2-52B, 2-145B, 2-146B, 2-149B, 2-163B, 2-164B, 2-165B, 2-166B, 2-173B, 2-264B, 2-265B, and 70 in the USZ; and 2-2A, 2-4A, 2-51A, 2-52A, and 2-149A in the LSZ. In addition, all newly installed monitoring points/wells at both sites will be sampled.

Sampling will be conducted by qualified scientists and technicians from Parsons ES and the USEPA NRMRL who are trained in the performance of groundwater sampling, records documentation, and chain-of-custody procedures. In addition, sampling personnel will have thoroughly reviewed this work plan prior to sample acquisition and will have a copy of the work plan available onsite for reference.

3.3.2 Preparation for Sampling

All equipment to be used for sampling will be assembled and properly cleaned and calibrated (if required) prior to arriving in the field. In addition, all record-keeping materials will be gathered prior to leaving the office.

3.3.2.1 Equipment Cleaning

All portions of sampling and test equipment that will contact the sample matrix will be thoroughly cleaned before each use. This includes split spoon samplers, water level probe and cable, test equipment for onsite use, and other equipment or portions thereof that will contact the samples. Based on the types of sample analyses to be conducted, the following cleaning protocol will be used:

- Wash with potable water and phosphate-free laboratory detergent (HP-II detergent solutions, as appropriate);
- Rinse with potable water;
- Rinse with isopropyl alcohol;
- Rinse with distilled or deionized water; and
- Air dry the equipment prior to use.

Any deviations from these procedures will be documented in the field scientist's field notebook and on the Groundwater Sampling Record (Figure 3.7).

If precleaned disposable sampling equipment is used, the cleaning protocol specified above will not be required. Laboratory-supplied sample containers will be cleaned and sealed by the laboratory. The type of container provided and the method of container decontamination will be documented in the laboratory's permanent record of the sampling event.

3.3.2.2 Equipment Calibration

As required, field analytical equipment will be calibrated according to the manufacturers' specifications prior to field use. This applies to equipment used for onsite measurements of DO, pH, electrical conductivity, alkalinity, redox potential, sulfate, nitrate, ferrous iron (Fe^{2+}), and other field parameters listed in Table 3.1.

3.3.3 Well and Monitoring Point Sampling Procedures

Special care will be taken to prevent contamination of the groundwater and extracted samples. The primary way in which sample contamination can occur is through cross-contamination due to insufficient cleaning of equipment between wells and monitoring points. To prevent such contamination, the water level probe and cable used to

Sampling Location: Tinker AFB FTA 2 / Area A
Sampling Dates: ____________________

GROUNDWATER SAMPLING RECORD - MONITORING WELL ____________________
(number)

REASON FOR SAMPLING: [ ] Regular Sampling; [ ] Special Sampling;
DATE AND TIME OF SAMPLING: __________ at ________ a.m./p.m.
SAMPLE COLLECTED BY: __________ of Parsons ES
WEATHER: ____________________
DATUM FOR WATER DEPTH MEASUREMENT (Describe): ____________________

MONITORING WELL CONDITION:
[ ] LOCKED: [ ] UNLOCKED
WELL NUMBER (IS - IS NOT) APPARENT
STEEL CASING CONDITION IS: ____________________
INNER PVC CASING CONDITION IS: ____________________
WATER DEPTH MEASUREMENT DATUM (IS - IS NOT) APPARENT
[ ] DEFICIENCIES CORRECTED BY SAMPLE COLLECTOR
[ ] MONITORING WELL REQUIRED REPAIR (describe): ____________________

Check-off
1 [ ] EQUIPMENT CLEANED BEFORE USE WITH ____________________
Items Cleaned (List): ____________________

2 [ ] PRODUCT DEPTH ____________________ FT. BELOW DATUM
Measured with: ____________________

WATER DEPTH ____________________ FT. BELOW DATUM
Measured with: ____________________

3 [ ] WATER-CONDITION BEFORE WELL EVACUATION (Describe):
Color: ____________________
Turbidity: ____________________
Odor: ____________________
Other Comments: ____________________

4 [ ] WELL EVACUATION:
Method: ____________________
Volume Removed: ____________________
Observations: Turbidity (clear slightly cloudy very cloudy)
Water level (rose fell no change)
Water odors: ____________________
Other comments: ____________________

FIGURE 3.7

GROUNDWATER SAMPLING RECORD

Sites FTA 2 and Area A
RNA TS
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Monitoring Well No. ______________ (Cont'd)

5 [ ] SAMPLE EXTRACTION METHOD:

[ ] Bailer made of:______________________________
[ ] Pump, type:______________________________
[ ] Other, describe:______________________________

Sample obtained is [X] GRAB; [ ] COMPOSITE SAMPLE

6 [ ] ON-SITE MEASUREMENTS:

Time						Measured with
Temp (°C)						
pH						
Cond (µS/cm)						
DO (mg/L)						
Redox (mV)						
Salinity						

7 [ ] SAMPLE CONTAINERS (material, number, size):______________________________

8 [ ] ON-SITE SAMPLE TREATMENT:

[ ] Filtration: Method______________ Containers:______________
Method______________ Containers:______________
Method______________ Containers:______________

[ ] Preservatives added:

Method______________ Containers:______________
Method______________ Containers:______________
Method______________ Containers:______________
Method______________ Containers:______________

9 [ ] CONTAINER HANDLING:

[ ] Container Sides Labeled
[ ] Container Lids Taped
[ ] Containers Placed in Ice Chest

10 [ ] OTHER COMMENTS:______________________________

FIGURE 3.7(Cont.)

GROUNDWATER SAMPLING RECORD

Sites FTA 2 and Area A
RNA TS
Tinker AFB, Oklahoma

PARSONS ENGINEERING SCIENCE, INC.

Denver, Colorado

determine static water levels and total well depths will be thoroughly cleaned before and after field use and between uses at different sampling locations according to the procedures presented in Section 3.3.2.1. In addition to the use of properly cleaned equipment, dedicated high-density polyethylene (HDPE) tubing will be used at each monitoring point sampling location where a peristaltic pump is used for purging and sampling. Existing dedicated Grundfos® Redi-Flo II® pumps will be utilized for purging and sampling existing site monitoring wells. A properly decontaminated Grundfos® Redi-Flo II® or two-stage electric pump may be used for purging newly installed monitoring wells; a peristaltic pump with dedicated HDPE tubing or a disposable bailer will be used to sample these wells. A clean pair of new, disposable nitrile or latex gloves will be worn each time a different well or monitoring point is sampled. The following paragraphs present the procedures to be followed for groundwater sample collection from groundwater monitoring wells and monitoring points. These activities will be performed in the order presented below. Exceptions to this procedure will be noted in the sampler's field notebook and the groundwater sampling form.

3.3.3.1 Preparation of Location

Prior to starting the sampling procedure, the area around the existing wells and new monitoring points will be cleared of foreign materials, such as brush, rocks, and debris. These procedures will prevent sampling equipment from inadvertently contacting debris around the monitoring well/point. In addition, the sampling location will be inspected for the integrity of the protective cover, lock, external surface seal, concrete pad, cap, datum reference, and internal surface seal.

3.3.3.2 Water Level and Total Depth Measurements

Prior to removing any water from the monitoring well or monitoring point, the static water level will be measured. An electric water level probe (or oil/water interface probe) will be used to measure the depth to groundwater below the datum to the nearest

0.01 foot. After measuring the static water level, the water level probe will be slowly lowered to the bottom of the monitoring well/point, and the depth will be measured to the nearest 0.01 foot. Based on these measurements, the volume of water to be purged from the monitoring well/point will be calculated. If mobile LNAPL is encountered, the thickness of the LNAPL layer will be measured, and the total depth of the well/point will not be measured to minimize contamination of the water column with LNAPL.

3.3.3.3 Purging Before Sampling

The volume of water contained within the monitoring well/point casing at the time of sampling will be calculated, and three times the calculated volume will be removed from the well/monitoring point. Purge waters will be handled in accordance with the procedures outlined in Section 3.1.3.

If a monitoring well/monitoring point is evacuated to a dry state during purging, the monitoring well/monitoring point will be allowed to recharge, and the sample will be collected as soon as sufficient water is present in the monitoring well or monitoring point to obtain the necessary sample quantity. Sample compositing or sampling over a lengthy period by accumulating small volumes of water at different times to obtain a sample of sufficient volume will not be allowed.

3.3.3.4 Sample Extraction

HDPE tubing and a peristaltic pump will be used to extract groundwater samples from the monitoring well points. The tubing will be lowered through the well and 0.75-inch-OD PVC monitoring point casing into the water gently to prevent splashing. The sample will be transferred directly into the appropriate sample container. The water will be carefully poured down the inner walls of the sample bottle to minimize aeration of the sample. Existing dedicated Grundfos® Redi-Flo II® pumps will be

utilized for existing site monitoring wells. A peristaltic pump with dedicated HDPE tubing or disposable bailers may be used for newly installed monitoring wells.

Unless other instructions are given by the analytical laboratory, sample containers will be completely filled so that no air space remains in the container. Excess water collected during sampling will be handled according to the procedures outlined in Section 3.1.3.

3.3.4 Onsite Groundwater Parameter Measurement

As indicated on Table 3.1, many of the groundwater chemical parameters will be measured onsite by USEPA NRMRL or Parsons ES personnel. Some of the measurements will be made with direct-reading meters, while others will be made using of a Hach® portable colorimeter in accordance with specific Hach® analytical procedures. These procedures will be described in the following subsections.

All glassware or plasticware used in the analyses will have been cleaned prior to sample collection by thoroughly washing with a solution of Alconox® and water, and rinsing with deionized water and ethanol to prevent interference or cross contamination between measurements. If concentrations of an analyte are above the range detectable by the titrimetric method, the analysis will be repeated by diluting the groundwater sample with double-distilled water until the analyte concentration falls to a level within the range of the method. All rinseate and sample reagents accumulated during groundwater analysis will be collected in glass containers fitted with screw caps. These waste containers will be clearly labeled as to their contents and carefully stored for later transfer to the approved disposal facility.

3.3.4.1 Dissolved Oxygen Measurements

DO measurements will be made using a meter with a downhole oxygen sensor or a sensor in a flow-through cell. Measurements will be taken before and following

groundwater sample acquisition. When DO measurements are taken in monitoring wells/points that have not yet been sampled, the existing monitoring wells/points will be purged until DO levels stabilize. DO measurements will be recorded on the groundwater sampling record (Figure 3.7)

3.3.4.2 pH, Temperature, and Specific Conductance

Because the pH, temperature, and specific conductance of a groundwater sample can change significantly within a short time following sample acquisition, these parameters will be measured in the field in unfiltered, unpreserved, "fresh" water collected by the same technique as the samples taken for laboratory analyses. The measurements will be made in a clean glass container separate from those intended for laboratory analysis, and the measured values will be recorded in the groundwater sampling record (Figure 3.7).

3.3.4.3 Carbon Dioxide Measurements

Carbon dioxide (CO_2) is a byproduct of biological reactions and can be used to evaluate the bioactivity of the groundwater system. CO_2 concentrations in groundwater will be measured in the field by experienced USEPA NRMRL or Parsons ES scientists via titrimetric analysis using CHEMetrics® Method 4500 (0 to 250 mg/L as CO_2), or equivalent.

3.3.4.4 Alkalinity Measurements

Alkalinity in groundwater helps buffer the groundwater system against acids generated through both aerobic and anaerobic biodegradation processes. Alkalinity of the groundwater sample will be measured in the laboratory (Table 3.1), or may be measured in the field by experienced USEPA NRMRL or Parsons ES scientists via titrimetric analysis using USEPA-approved Hach® Method 8221 (0 to 5,000 mg/L as calcium carbonate), or equivalent.

3.3.4.5 Nitrate- and Nitrite-Nitrogen Measurements

Nitrate-nitrogen concentrations are of interest because nitrate can act as an electron acceptor during hydrocarbon biodegradation under anaerobic soil or groundwater conditions. Nitrate-nitrogen is also a potential nitrogen source for hydrocarbon-degrading bacteria biomass formation. Nitrite-nitrogen is an intermediate byproduct in both ammonia nitrification and in nitrate reduction in anaerobic environments.

Nitrate- and nitrite-nitrogen concentrations in groundwater will be measured in the laboratory (Table 3.1), or may be measured in the field by experienced NRMRL or Parsons ES scientists via colorimetric analysis using a Hach® DR/700 Portable Colorimeter. Nitrate concentrations in groundwater samples will be analyzed after preparation with Hach® Method 8039 (0 to 30.0 mg/L nitrate), or equivalent. Nitrite concentrations in groundwater samples will be analyzed after preparation with USEPA-approved Hach® Method 8507 (0 to 0.35 mg/L nitrite), or equivalent.

3.3.4.6 Sulfate and Sulfide Sulfur Measurements

Sulfate in groundwater is a potential electron acceptor for fuel-hydrocarbon biodegradation in anaerobic environments, and sulfide is resultant after sulfate reduction. Sulfate will be measured in the laboratory (Table 3.1), or USEPA NRMRL or Parsons ES scientists may measure sulfate and sulfide concentrations via colorimetric analysis with a Hach® DR/700 Portable Colorimeter after appropriate sample preparation. USEPA-approved Hach® Methods 8051 (0 to 70.0 mg/L sulfate) and 8131 (0.60 mg/L sulfide), or equivalents, will be used to prepare samples and analyze sulfate and sulfide concentrations, respectively.

3.3.4.7 Total Iron, Ferrous Iron, and Ferric Iron Measurements

Iron is an important trace nutrient for bacterial growth, and different states of iron can affect the oxidation/reduction potential of the groundwater and act as an electron acceptor for biological metabolism under anaerobic conditions. Iron concentrations

will be measured in the field via colorimetric analysis with a Hach® DR/700 Portable Colorimeter after appropriate sample preparation. Hach® Method 8008, or equivalent, for total soluble iron (0 to 3.0 mg/L ferric + ferrous iron) and Hach® Method 8146, or equivalent, for ferrous iron (0 to 3.0 mg/L) will be used to prepare and quantitate the samples. Ferric iron will be quantitated by subtracting ferrous iron levels from total iron levels.

3.3.4.8 Manganese Measurements

Manganese is a potential electron acceptor under anaerobic environments. Manganese concentrations will be quantitated in the field using colorimetric analysis with a Hach® DR/700 Portable Colorimeter. USEPA-approved Hach® Method 8034 (0 to 20.0 mg/L), or equivalent, will be used to prepare the samples for quantitation of manganese concentrations.

3.3.4.9 Oxidation/Reduction Potential

The ORP of groundwater is an indicator of the relative tendency of a solution to accept or transfer electrons. Redox reactions in groundwater are usually biologically mediated; therefore, the redox potential of a groundwater system depends upon and influences rates of biodegradation. ORPs can be used to provide real-time data on the location of the contaminant plume, especially in areas undergoing anaerobic biodegradation. The ORP of a groundwater sample taken inside the contaminant plume should be somewhat lower than that of a sample taken in an upgradient location.

The ORP of a groundwater sample can change significantly within a short time following sample acquisition and exposure to atmospheric oxygen. Therefore, this parameter will be measured in the field in unfiltered, unpreserved, "fresh" water collected by the same technique as the samples taken for laboratory analyses. The measurements will be made as quickly as possible in a clean glass container separate from those intended for laboratory analysis.

3.4 MOBILE LNAPL SAMPLING

If a sufficient thickness of mobile LNAPL is detected in a monitoring well at Area A, a sample of mobile LNAPL will be obtained using a disposable Teflon® bailer attached to nylon rope. The bailer will be gently lowered into the well in an attempt to minimize agitation. After the mobile LNAPL sample has been collected into the bailer and the bailer has been retrieved, any water accumulated in the bailer will be drained, and the LNAPL sample will be slowly poured into appropriate bottles. Sample packaging, labeling, and handling is described in the following section.

3.5 HANDLING OF SAMPLES FOR LABORATORY ANALYSIS

This section describes the handling of samples from the time of sampling until the samples are delivered to USEPA field laboratory.

3.5.1 Sample Preservation

The USEPA laboratory support personnel will add any necessary chemical preservatives prior to sealing the sample containers. Samples will be prepared for transportation to the analytical laboratory by placing the samples in a cooler containing ice to maintain a shipping temperature of as close to 4 degrees centigrade (°C) as possible. Samples will be delivered promptly to USEPA field laboratory personnel, who will be responsible for shipment of appropriate samples to the NRMRL in Ada, Oklahoma for analysis.

3.5.2 Sample Container and Labels

Sample containers and appropriate container lids will be provided by the USEPA field laboratory (see Appendix A). The sample containers will be filled as described in Sections 3.1.2 and 3.3.3.4, and the container lids will be tightly closed. The sample

label will be firmly attached to the container side, and the following information will be legibly and indelibly written on the label:

- Facility name;
- Sample identification;
- Sample type (e.g., groundwater, soil);
- Sampling date;
- Sampling time;
- Preservatives added;
- Sample collector's initials; and
- Analyses requested.

3.5.3 Sample Shipment

After the samples are sealed and labeled, they will be packaged for transport to the onsite USEPA field laboratory. The packaged samples will be delivered by hand to the USEPA field laboratory. Delivery will occur as soon as possible after sample acquisition.

The following packaging and labeling procedures will be followed:

- Package sample so that it will not leak, spill, or vaporize from its container;
- Cushion samples to avoid breakage; and
- Add ice to container to keep samples cool.

USEPA personnel will be responsible for repackaging and overnight shipment of samples to the NRMRL in Ada, Oklahoma.

3.5.4 Chain-of-Custody Control

Chain-of-custody documentation for the shipment of samples from the USEPA field laboratory to the NRMRL analytical laboratory in Ada, Oklahoma, will be the responsibility of the USEPA field personnel.

3.5.5 Sampling Records

In order to provide complete documentation of the sampling event, detailed records will be maintained by the field scientist. At a minimum, these records will include the following information:

- Sample location (facility name);
- Sample identification;
- Sample location map or detailed sketch;
- Date and time of sampling;
- Sampling method;
- Field observations of
  - Sample appearance, and
  - Sample odor;
- Weather conditions;
- Water level prior to purging (groundwater samples, only);

- Total monitoring well/point depth (groundwater samples, only);
- Sample depth (soil samples, only);
- Purge volume (groundwater samples, only);
- Water level after purging (groundwater samples, only);
- Monitoring well/point condition (groundwater samples, only);
- Sampler's identification;
- Field measurements of pH, temperature, DO, and specific conductivity (groundwater samples, only); and
- Any other relevant information.

Groundwater sampling information will be recorded on a groundwater sampling form. Figure 3.7 shows an example of the groundwater sampling record. Soil sampling information will be recorded in the field log book.

3.5.6 Laboratory Analyses

Laboratory analyses will be performed on all groundwater and soil samples as well as the QA/QC samples described in Section 4. The analytical methods for this sampling event are listed in Table 3.1. Prior to sampling, USEPA NRMRL personnel will provide a sufficient number of analyte-appropriate sample containers for the samples to be collected. All containers, preservatives, and shipping requirements will be consistent with USEPA protocol or those listed in Appendix B of this plan.

USEPA laboratory support personnel will specify the necessary QC samples and prepare appropriate QC sample containers. For samples requiring chemical

preservation, preservatives will be added to containers by the laboratory or USEPA NRMRL field personnel. Containers, ice chests with adequate padding, and cooling media will be provided by USEPA NRMRL laboratory personnel. Sampling personnel will fill the sample containers and return the samples to the field laboratory.

3.6 AQUIFER TESTING

Slug tests will be conducted on newly installed monitoring wells at each site to estimate the hydraulic conductivity of unconsolidated deposits at the sites. This information is required to accurately estimate the velocity of groundwater and contaminants in the shallow saturated zone. A slug test is a single-well hydraulic test used to determine the hydraulic conductivity of an aquifer in the immediate vicinity of the tested well. Slug tests can be used for both confined and unconfined aquifers that have a transmissivity of less than 7,000 square feet per day (ft^2/day). Slug testing can be performed using either a rising head or a falling head test; at this site, both methods will be used in sequence.

3.6.1 Definitions

- **Hydraulic Conductivity (K)**. A quantitative measure of the ability of porous material to transmit water; defined as the volume of water that will flow through a unit cross-sectional area of porous or fractured material per unit time under a unit hydraulic gradient.

- **Transmissivity (T)**. A quantitative measure of the ability of an aquifer to transmit water. It is the product of the hydraulic conductivity and the saturated thickness.

- **Slug Test**. Two types of testing are possible: rising head and falling head tests. A slug test consists of adding a slug of water or a solid cylinder of known volume to the well to be tested or removing a known volume of water or cylinder and

measuring the rate of recovery of water level inside the well. The slug of a known volume acts to raise or lower the water level in the well.

- **Rising Head Test**. A test used in an individual well within the saturated zone to estimate the hydraulic conductivity of the surrounding formation by lowering the water level in the well and measuring the rate of recovery of the water level. The water level may be lowered by pumping, bailing, or removing a submerged slug from the well.

- **Falling Head Test**. A test used in an individual well to estimate the hydraulic conductivity of the surrounding formation by raising the water level in the well by insertion of a slug or quantity of water, and then measuring the rate of drop in the water level.

3.6.2 Equipment

The following equipment will be used to conduct a slug test:

- Teflon®, PVC, or metal slugs;

- Nylon or polypropylene rope;

- Electric water level indicator;

- Pressure transducer/sensor;

- Field logbook/forms; and

- Automatic data recording instrument (such as the Hermit Environmental Data Logger®, In-Situ, Inc. Model SE1000B, or equivalent).

3.6.3 General Test Methods

Aquifer hydraulic conductivity tests (slug tests) are accomplished by either removal of a slug or quantity of water (rising head) or introduction of a slug (falling head), and then allowing the water level to stabilize while taking water level measurements at closely spaced time intervals.

Because hydraulic testing will be completed on existing wells, it will be assumed that the wells were properly developed and that water levels have stabilized. Slug testing will proceed only after multiple water level measurements over time show that static water levels are in equilibrium. During the slug test, the water level change should be influenced only by the introduction (or removal) of the slug volume. Other factors, such as inadequate well development or extended pumping may lead to inaccurate results; in addition, slug tests will not be performed on wells with free product. The field scientist will determine when static equilibrium has been reached in the well. The pressure transducer, slugs, and any other downhole equipment will be decontaminated prior to and immediately after the performance of each slug test using the procedures described in Section 3.1.3.

3.6.4 Falling Head Test

The falling head test is the first step in the two-step slug testing procedure. The following steps describe procedures to be followed during performance of the falling head test.

1. Decontaminate all downhole equipment prior to initiating the test.

2. Open the well. Where wells are equipped with watertight caps, the well should be unsealed at least 24 hours prior to testing to allow the water level to stabilize. The protective casing will remain locked during this time to prevent vandalism.

3. Prepare the aquifer slug test data form (Figure 3.8) with entries for:

   - Borehole/well number,
   - Project number,
   - Project name,
   - Aquifer testing team,
   - Climatic data,
   - Ground surface elevation,
   - Top of well casing elevation,
   - Identification of measuring equipment being used,
   - Static water level, and
   - Date.

4. Measure the static water level in the well to the nearest 0.01 foot.

5. Lower the decontaminated pressure transducer into the well and allow the displaced water to return to its static level. This can be determined by periodic water level measurements until the static water level in the well is within 0.01 foot of the original static water level.

6. Lower the decontaminated slug into the well to just above the water level in the well.

Aquifer Slug Test Data Sheet

Location Tinker AFB FTA 2 / Area A
Client AFCEE/RNA
Well No.____________
Job No. 729691.34020
Field Scientist ________
Date____________
Water Level________________
Total Well Depth________________
Measuring Datum________________
Elevation of Datum________________
Weather________________
Temperature________________
Comments________________________________

Beginning Time	Ending Time	Initial Head Reading	Ending Head Reading	Test Type (Rise/Fall)	File Name	Comments

FIGURE 3.8

AQUIFER SLUG TEST DATA SHEET

Sites FTA 2 and Area A
RNA TS
Tinker AFB, Oklahoma

PARSONS ENGINEERING SCIENCE, INC.
Denver, Colorado

7. Turn on the data logger and quickly lower the slug below the water table, being careful not to disturb the pressure transducer. Follow the owner's manual for proper operation of the data logger.

8. Terminate data recording when the water level stabilizes in the well. The well will be considered stabilized for termination purposes when it has recovered 80 to 90 percent from the initial displacement.

3.6.5 Rising Head Test

After completion of the falling head test, the rising head test will be performed. The following steps describe the rising head slug test procedure.

1. Measure the water level in the well to the nearest 0.01 foot to ensure that it has returned to the static water level.

2. Initiate data recording and quickly withdraw the slug from the well. Follow the owner's manual for proper operation of the data logger.

3. Terminate data recording when the water level stabilizes in the well, and remove the pressure transducer from the well and decontaminate. The well will be considered stabilized for termination purposes when it has recovered 80 to 90 percent from the initial displacement.

3.6.6 Slug Test Data Analysis

Data obtained during slug testing will be analyzed using AQTESOLV™ and the method of Hvorslev (1951) for confined aquifers or the method of Bouwer and Rice (1976) and Bouwer (1989) for unconfined conditions.

SECTION 4

QUALITY ASSURANCE/QUALITY CONTROL

Field QA/QC procedures will include collection of field duplicates/replicates and rinseate, field, and trip blanks; decontamination of all equipment that contacts the sample medium before and after each use; use of analyte-appropriate containers; and chain-of-custody procedures for sample handling and tracking. All samples to be transferred to the USEPA laboratory for analysis will be clearly labeled to indicate sample number, location, matrix (e.g., groundwater), and analyses requested. Samples will be preserved in accordance with the analytical methods to be used, and water sample containers will be packaged in coolers with ice to maintain a temperature of as close to 4°C as possible.

All field sampling activities will be recorded in a bound, sequentially paginated field notebook in permanent ink. All sample collection entries will include the date, time, sample locations and numbers, notations of field observations, and the sampler's name and signature. Field QC samples will be collected in accordance with the program described below, and as summarized in Table 4.1.

QA/QC sampling will include collection and analysis of duplicate groundwater and replicate soil samples, rinseate blanks, field/trip blanks, and matrix spike samples. Internal laboratory QC analyses will involve the analysis of laboratory control samples (LCSs) and laboratory method blanks (LMBs). QA/QC objectives for each of these samples, blanks, and spikes are described below.

TABLE 4.1
QA/QC SAMPLING PROGRAM
SITES FTA 2 AND AREA A
RNA TS
TINKER AFB, OKLAHOMA

QA/QC Sample Type	Frequency to be Collected and Analyzed [a/]	Analytes
Duplicates/Replicates	10% of Groundwater and Soil Samples	VOCs, TPH, PAHs, Methane, Geochemical
Rinseate Blanks	5% of Groundwater Samples	VOCs
Field Blanks	5% of Groundwater Samples	VOCs
Trip Blanks	One per shipping cooler containing VOC samples	VOCs
Matrix Spike Samples	One per sampling event	VOCs
Laboratory Control Sample	One per method per medium	Laboratory Control Charts (Method Specific)
Laboratory Method Blanks	One per method per medium	Laboratory Control Charts (Method Specific)

a/ Actual frequency of QA/QC samples may be altered by the USEPA field scientists.

C:\TINKER\WORKPLAN\1.XLS

Duplicate groundwater and replicate soil samples will be collected at a frequency of 1 for every 10 or fewer samples of similar matrix. Each duplicate groundwater sample will be collected concurrent with, and by the same method, as the primary sample. Replicated soil samples will be collected by mixing a single soil sample interval to obtain a homogeneous sample, and then dividing the soil sample into the primary and replicate soil sample containers. For samples to be analyzed for VOCs, mixing of the soil will be minimized to prevent the loss of volatiles. Duplicate samples will be analyzed for VOCs and geochemical analyses.

One rinseate sample will be collected for every 20 or fewer groundwater samples collected. Because both peristaltic pumps and disposable bailers may be used for this sampling event, the rinseate samples will alternately consist of a sample representing both methods. The peristaltic pump sample will consist of a sample of distilled water pumped through a section of clean tubing and subsequently transferred into a sample container provided by the laboratory. The disposable bailer sample will consist of a sample of distilled water poured into a new disposable bailer and subsequently transferred into a sample container provided by the laboratory. Rinseate samples will be analyzed for VOCs only.

One field blank will be collected for every 20 or fewer groundwater samples to assess the effects of ambient conditions in the field. The field blank will consist of a sample of distilled water poured into a laboratory-supplied sample container while sampling activities are underway. The field blank will be analyzed for VOCs.

A trip blank will be analyzed to assess the effects of ambient conditions on sampling results during the transportation of samples. The trip blank will be prepared by the laboratory. A trip blank will be transported inside each cooler which contains samples for VOC analysis. Trip blanks will be analyzed for VOCs.

Matrix spikes will be prepared in the laboratory and used to establish matrix effects for samples analyzed for VOCs. LCSs and LMBs will be prepared internally by the laboratory and will be analyzed each day samples from the sites are analyzed. Samples will be reanalyzed in cases where the LCS or LMB are out of the control limits. Control charts for LCSs and LMBs will be developed by the laboratory and monitored for the analytical methods used (see Table 3.1).

SECTION 5

DATA ANALYSIS AND REPORT

Once the data collected during the field effort are assembled, they will be analyzed using a variety of methods. For example, isopleth maps of BTEX and CAHs, degradation products, and primary and alternate electron acceptors and donors will be used to evaluate the occurrence and mechanisms of biodegradation at the site, using the relationships discussed in Section 2. In addition, the Thiessen method will be used to estimate contaminant mass in the plume, using data from the latest sampling event and from previous sampling events. The Thiessen method also may be used to evaluate movement of the center of mass of the CAH plume over time, as presented by Dupont *et al.* (1996a and 1996b). This information will give an indication of how contaminant plumes have changed over time, and whether the plumes are stable. If it is apparent that contaminant mass is being lost over time, then it is highly likely that biodegradation is occurring. Site contaminant data also will be used to determine rates of contaminant mass loss and to determine rates of biodegradation. Site data also will be used to estimate contaminant flux through specified areas. Where possible, the data also will be applied to estimate the impacts of other ongoing or planned remedial actions at Sites FTA 2 and Area A.

After the data evaluation and analysis, numerical and/or analytical groundwater models will be used to evaluate the fate and transport of fuel hydrocarbons and chlorinated solvents dissolved in groundwater at both sites. The contaminant fate and transport modeling effort has three primary objectives: 1) predict the future extent and concentration of dissolved contaminant plumes by modeling the effects of advection,

dispersion, sorption, and biodegradation; 2) assess the possible exposure of potential downgradient receptors to contaminant concentrations that exceed levels intended to be protective of human health and the environment; and 3) to provide technical support for selection of RNA as the best remedial alternative at regulatory negotiations, as appropriate.

Based upon model predictions of contaminant concentrations and distribution through time, and upon potential exposure pathways, the potential risk to human health and the environment will be assessed. If it is shown that RNA of BTEX compounds and CAHs at FTA 2 and Area A is sufficient to reduce the potential risk to human health and the environment to acceptable levels, Parsons ES will recommend implementation of the RNA with LTM option. If RNA is chosen, Parsons ES will prepare site-specific, LTM plans that will specify the location of point-of-compliance monitoring wells and sampling frequencies.

If RNA alone is deemed inappropriate for use at these sites, institutional controls such as groundwater or land use restrictions will be evaluated to determine if they will be sufficient to reduce the risk to human health and the environment to acceptable levels. If institutional controls are inappropriate, remedial options that could reduce risks to acceptable levels will be evaluated, and appropriate remedial options will be recommended. Potential remedial options include, but are not limited to: free product recovery (e.g., bioslurping), groundwater pump-and-treat, enhanced biological treatment, air sparging, and *in situ* reactive barrier walls. The reduction in dissolved BTEX and CAHs that should result from remedial activities will be used to produce new input files for the groundwater models. The models will then be used to predict the BTEX and CAH plume, and risk, reduction that should result from remedial actions.

A report detailing the results of the modeling and remedial option evaluation will be prepared. This report will follow the outline presented in Table 5.1 and will contain an introduction, site descriptions, identification of remediation objectives, description of remediation alternatives, an analysis of remediation alternatives, and the suggested remedial approach for each site. This report will also contain the results of the site characterization activities described herein.

TABLE 5.1
EXAMPLE REPORT OUTLINE
SITES FTA 2 AND AREA A
RNA TS
TINKER AFB, OKLAHOMA

INTRODUCTION
- Scope and Objectives
- Site Background

SITE CHARACTERIZATION ACTIVITIES
- Sampling and Aquifer Testing Procedures

PHYSICAL CHARACTERISTICS OF THE STUDY AREA
- Surface Features
- Regional Geology and Hydrogeology
- Site Geology and Hydrogeology
- Climatological Characteristics

NATURE AND EXTENT OF CONTAMINATION
- Source Characterization
- Soil and Source Chemistry (if source is located)
    - Residual Contamination
    - Total Organic Carbon
- Groundwater Chemistry
    - Dissolved Contamination
    - Groundwater Geochemistry
- Discussion of Results
    - Evidence of Biodegradation/Cometabolism
    - Calculation of Biodegradation Rates
    - Expressed Assimilative Capacity

GROUNDWATER FLOW AND SOLUTE TRANSPORT MODELING
- Model Description
- Conceptual Model Design and Assumptions
- Initial Model Setup
- Model Calibration
- Sensitivity Analysis
- Model Results
- Conclusions

TABLE 5.1 (Continued)
EXAMPLE REPORT OUTLINE
SITES FTA 2 AND AREA A
RNA TS
TINKER AFB, OKLAHOMA

COMPARATIVE ANALYSIS OF REMEDIAL ALTERNATIVES
- Remedial Alternatives Evaluation Criteria
  - Long-Term Effectiveness
  - Implementability (Technical, Administrative)
  - Cost (Capital, Operating, Present Worth)
- Factors Influencing Alternatives Development
  - Program Objectives
  - Contaminant Properties
  - Site-Specific Conditions
- Brief Description of Remedial Alternatives
  - Intrinsic Remediation with Long-Term Monitoring
  - Other Alternatives
- Evaluation of Alternatives
- Recommended Remedial Approach

LONG-TERM MONITORING PLAN
- Overview
- Monitoring Networks
- Groundwater and Surface Water Sampling

CONCLUSIONS AND RECOMMENDATIONS

APPENDICES: Supporting Data and Documentation
Site-Specific Model Input and Results

SECTION 6

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APPENDIX A

CONTAINERS, PRESERVATIVES, PACKAGING, AND SHIPPING REQUIREMENTS FOR GROUNDWATER SAMPLES

APPENDIX A

ANALYTICAL METHODS, DATA USE, AND SAMPLE PACKAGING

REQUIREMENTS FOR SOIL AND WATER SAMPLES

Matrix	Analysis	Method/Reference	Comments	Data Use	Recommended Frequency of Analysis	Sample Volume, Sample Container, Sample Preservation	Field or Fixed-Base Laboratory
Soil	Total volatile and extractable hydrocarbons,	Gas chromatography (GC) method SW8015 [modified]	Handbook method; reference is the California LUFT manual	Data are used to determine the extent of soil contamination, the contaminant mass present, and the need for source removal	Each soil sampling round	Collect 100 g of soil in a glass container with Teflon-lined cap; cool to 4°C	Fixed-base
Soil	Aromatic and Chlorinated hydrocarbons ([BTEX, PCE, TCE, DCE, VC)	Purge and trap GC method SW8240	Handbook method modified for field extraction of soil using methanol	Data are used to determine the extent of soil contamination, the contaminant mass present, and the need for source removal	Each soil sampling round	Collect 100 g of soil in a glass container with Teflon-lined cap; cool to 4°C	Fixed-base
Soil	Total organic carbon (TOC)	SW9060 modified for soil samples	Procedure must be accurate over the range of 0.01–15 percent TOC	The rate of migration of petroleum contaminants in groundwater is dependent upon the amount of TOC in the aquifer matrix.	At initial sampling	Collect 100 g of soil in a glass container with Teflon-lined cap; cool to 4°C	Fixed-base
Soil	Moisture	ASTM D-2216	Handbook method	Data are used to correct soil sample analytical results for moisture content (e.g., report results on a dry weight basis).	Each soil sampling round	Use a portion of soil sample collected for another analysis	Fixed-base

APPENDIX A (continued)

Matrix	Analysis	Method/Reference	Comments	Data Use	Recommended Frequency of Analysis	Sample Volume, Sample Container, Sample Preservation	Field or Fixed-Base Laboratory
Water	Aromatic and chlorinated hydrocarbons (BTEX, trimethylbenzene isomers, PCE, TCE, DCE, VC, chloromethane, chloroform, other relevant compounds)	Methods SW8010/8020 or SW8240	Handbook methods; analysis may be extended to higher molecular weight alkylbenzenes	Method of analysis for BTEX & CAHs, which are the primary target analytes for monitoring natural attenuation; BTEX & CAH concentrations must also be measured for regulatory compliance; trimethylbenzenes are used to monitor BTEX plume dilution if degradation is primarily anaerobic. Chloromethane and chloroform are indicators of CAH contamination by aerobic pathways.	Each sampling round	Collect water samples in a 40 mL VOA vial; cool to 4°C; add hydrochloric acid to pH 2	Fixed-base
Water	Polycyclic aromatic hydrocarbons (PAHs) (optional)	GC/mass spectroscopy method SW8270; high-performance liquid chromatography method SW8310	Analysis needed only when required for regulatory compliance.	PAHs are components of fuel and are typically analyzed for regulatory compliance; data on their concentrations are not used currently in the evaluation of natural attenuation.	As required by regulations	Collect 1 L of water in a glass container; cool to 4°C	Fixed-base
Water	Oxygen	Dissolved oxygen meter	Refer to method A4500 for a comparable laboratory procedure.	The oxygen concentration is a data input to the Bioplume model; concentrations less than 1 mg/L generally indicate an anaerobic pathway.	Each sampling round	Measure dissolved oxygen on site using a flow-through cell	Field

APPENDIX A (continued)

Matrix	Analysis	Method/Reference	Comments	Data Use	Recommended Frequency of Analysis	Sample Volume, Sample Container, Sample Preservation	Field or Fixed-Base Laboratory
Water	Nitrate	IC method E300	Method E300 is a Handbook method.	Substrate for microbial respiration if oxygen is depleted.	Each sampling round	Collect up to 40 mL of water in a glass or plastic container; add H_2SO_4 to pH 2, cool to 4°C	Fixed-base
Water	Iron (II) (Fe^{+2})	Colorimetric Hach Method # 8146	Filter if turbid.	May indicate an anaerobic degradation process due to depletion of oxygen, and nitrate.	Each sampling round	Collect 100 mL of water in a glass container	Field
Water	Sulfate (SO_4^{-2})	IC method E300	Method E300 is a Handbook method, if this method is used for sulfate analysis, do not use the field method.	Substrate for anaerobic microbial respiration	Each sampling round	Collect up to 40 mL of water in a glass or plastic container; cool to 4°C	Fixed-base
Water	Sulfate (SO_4^{-2})	Hach method # 8051	Colorimetric, if this method is used for sulfate analysis, do not use the fixed-base laboratory method.	Same as above	Each sampling round	Collect up to 40 mL of water in a glass or plastic container; cool to 4°C	Field
Water	Methane, ethane, and ethene	Kampbell *et al.*, 1989 or SW3810 Modified	Method published by researchers at the US Environmental Protection Agency.	The presence of CH_4 suggests BTEX or other carbon degradation via methanogenesis. Ethane and ethene data are used where chlorinated solvents are suspected of undergoing anaerobic biological transformation.	Each sampling round	Collect water samples in 50 mL glass serum bottles with butyl gray/Teflon-lined caps; add H_2SO_4 to pH 2, cool to 4°C	Fixed-base

APPENDIX A (continued)

Matrix	Analysis	Method/Reference	Comments	Data Use	Recommended Frequency of Analysis	Sample Volume, Sample Container, Sample Preservation	Field or Fixed-Base Laboratory
Water	Carbon dioxide	Hach test kit model CA-23; Chemetrics Method R-1910	Titrimetric; alternate method	The presence of free CO_2 dissolved in groundwater is unlikely because of the carbonate buffering system of water, but if detected, the CO_2 concentrations should be compared with background levels to determine if they are elevated; elevated concentrations of CO_2 could indicate biodegradation of dissolved contaminants.	Each sampling round	Collect 100 mL of water in a glass container	Field
Water	Alkalinity	Hach Alkalinity test kit model AL AP MG-L	Phenolphthalein method	General water quality parameter used (1) as a marker to verify that all site samples are obtained from the same groundwater system and (2) to measure the buffering capacity of groundwater.	Each sampling round	Collect 100 mL of water in glass container	Field
Water	Oxidation-reduction potential (ORP)	A2580B	Measurements made with electrodes; results are displayed on a meter; protect samples from exposure to oxygen. Report results against a silver/silver chloride reference electrode	The ORP of groundwater influences and is influenced by the nature of the biologically mediated degradation of contaminants; the ORP of groundwater may range from more than 800 mV to less than -400 mV.	Each sampling round	Collect 100–250 mL of water in a glass container, filling container from bottom; analyze immediately	Field

APPENDIX A (continued)

Matrix	Analysis	Method/Reference	Comments	Data Use	Recommended Frequency of Analysis	Sample Volume, Sample Container, Sample Preservation	Field or Fixed-Base Laboratory
Water	pH	Field probe with direct reading meter.	Field	Aerobic and anaerobic processes are pH-sensitive.	Each sampling round	Collect 100–250 mL of water in a glass or plastic container; analyze immediately	Field
Water	Temperature	Field probe with direct reading meter.	Field only	Well development.	Each sampling round	Not Applicable	Field
Water	Conductivity	E120.1/SW9050, direct reading meter	Protocols/Handbook methods	General water quality parameter used as a marker to verify that site samples are obtained from the same groundwater system.	Each sampling round	Collect 100–250 mL of water in a glass or plastic container	Field
Water	Chloride	Mercuric nitrate titration A4500-Cl^- C	Ion chromatography (IC) method E300 or method SW9050 may also be used	General water quality parameter used as a marker to verify that site samples are obtained from the same groundwater system; elevated concentrations may also indicate biodegradation of CAHs.	Each sampling round	Collect 250 mL of water in a glass container	Fixed-base
Water	Chloride (optional, see data use)	Hach Chloride test kit model 8-P	Silver nitrate titration	As above, and to guide selection of additional data points in real time while in the field.	Each sampling round	Collect 100mL of water in a glass container	Field
Water	Total Organic Carbon		Laboratory	Used to classify plume and to determine if CAH biodegradation is possible in the absence of anthropogenic carbon.	Each sampling round	Collect 100 mL of water in a glass container, cool	Laboratory

APPENDIX A (concluded)

Matrix	Analysis	Method/Reference	Comments	Data Use	Recommended Frequency of Analysis	Sample Volume, Sample Container, Sample Preservation	Field or Fixed-Base Laboratory
ADDITIONAL (OPTIONAL) ANALYSES							
Water	Biochemical Oxygen Demand	EPA Method 405.1			Each sampling round	Collect 2 L of water in a glass container, cool	Laboratory
Water	Hydrogen (H_2)		Relatively new analysis; data useful for evaluating biodegradation processes operating at a given time	Indicator of terminal electron-accepting processes operating at a site.	Each sampling round	to be determined	
Water	Oxygenates (including methanol and acetone)	Optional; SW 8015 Modified			Each sampling round	Collect water samples in a 40 mL VOA vial; cool to 4°C; add hydrochloric acid to pH 2	Laboratory
Water	Alcohols, ethers, and acetic acids	Optional; SW 8015 Modified		Optional carbon sources for biodegradation.	Each sampling round	Collect water samples in a 40 mL VOA vial; cool to 4°C; add hydrochloric acid to pH 2	Laboratory
Water	Acetaldehydes	Optional; GC/MS method to be determined			Each sampling round	to be determined	Laboratory
Water	Aliphatic Fatty Acids	Optional; GC/MS method to be determined		Byproducts of biodegradation processes; indicators of biodegradation and cometabolism.	Each sampling round	to be determined	Laboratory
Water	Organic Acids	Optional; GC/MS method to be determined		Optional carbon sources and byproducts of biodegradation processes.	Each sampling round	to be determined	Laboratory

NOTES:

* Analyses other than those listed in this table may be required for regulatory compliance.

1. "Hach" refers to the Hach Company catalog, 1990.
2. "A" refers to *Standard Methods for the Examination of Water and Wastewater*, 18th edition, 1992.
3. "E" refers to *Methods for Chemical Analysis of Water and Wastes*, USEPA, 1983.
4. "Protocols" refers to the AFCEE *Environmental Chemistry Function Installation Restoration Program Analytical Protocols*, 11 June 1992.
5. "Handbook" refers to the AFCEE *Handbook to Support the Installation Restoration Program (IRP) Remedial Investigations and Feasibility Studies (RI/FS)*, September 1993.
6. "SW" refers to the *Test Methods for Evaluating Solid Waste, Physical, and Chemical Methods*, SW-846, USEPA, 3rd edition, 1986.
7. "ASTM" refers to the *American Society for Testing and Materials*.
8. "LUFT" refers to the State of California *Leaking Underground Fuel Tank Field Manual*, 1988 edition.

APPENDIX B

ADDITIONAL SITE DATA
SITE FTA 2

Client: TINKER AFB
Project Name: TINKER 5001
Project Location: TINKER AFB, OKLAHOMA
Project Number: 409832

MONITORING WELL 2-62B

DRILLING AND SAMPLING INFORMATION

Boring Location: EAST OF FIRE TRAINING AREA
SURFACE ELEV.(FT): 1245.940
TOTAL DEPTH(FT.): 33.0
Logged By: K. KIRSCHENMANN
Date Started: 11/9/93
Drilled By: P. GUERREIN GEOTECHNOLOGY, INC.
Date Completed: 11/9/93
Drill Rig Type: CME-75
Drilling Method: 8" HOLLOW STEM AUGER

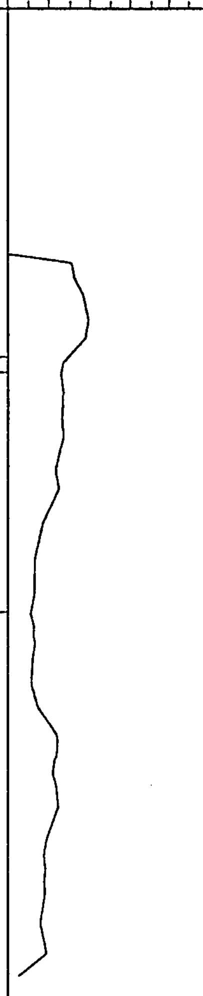
Sampling Method: 3"x5' CONTINUOUS SAMPLER

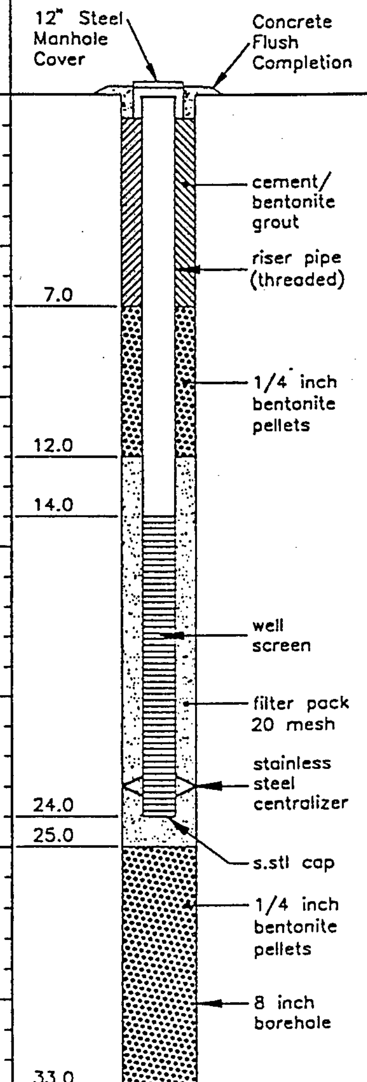
Notes: N 150444.517, E 2182140.558

WELL COMPLETION DATA

Elev-Top of Casing(ft.): Ref. Datum: MSL
1. Riser Pipe-I.D.(in.): 2 Depth(ft.): 14 Type: S.Steel
Centralizers-Type: Depths(ft.):
2. Screen Dia.(in.): 2 Type: S.Steel Millslotted
Depth Interval(ft.): 14-24 Slot Size(in.): .010
Centralizers-Type: S.Steel Depths(ft.): 23
3. Filter Pack Type: Silica Sand Depth Interval(ft.): 12-25
Conc. Pad Size: 4'x4'x6"

DESCRIPTION	GEOPHYSICAL LOG (GAMMA) 10 20 30 40	SAMPLE TYPE / SAMPLE NO.	IN. DRIVEN / IN. RECOVERED	PID, PPM	USCS	GRAPHIC LOG	DEPTH IN FEET
SILTY CLAY - nonplastic; hard; slightly moist; strong brown (7.5YR-4/6) - dark red (2.5YR-4/8); gradational contact			42 / 42		cl		0–11.5
- 10% very fine grained sand; very hard; dry;			60 / 60				5
			54 / 54				10
SAND - very fine grained; 5% silt and clay; compact; dry; pale yellow (2.5Y-7/3); sharp contact					sw		
SILTY CLAY - nonplastic; 10% very fine grained sand; very hard; dry; dark red (2.5YR-4/8); sharp contact - switched to center bit at 13.0' (very hard drilling) - alternating very hard layers (17.0-20.0')					cl		15
SILTY SAND - approximate level of water bearing sediments					sm		20–33
TOTAL DEPTH = 33.0 FEET							





DRAFT BY	RPS 12/1/93	DRAFT CHK		PROJ. CHK		APPRV. BY		DWG. NO.	409832-A30 Sheet 1 of 1

Client: TINKER AFB
Project Name: TINKER 5001
Project Location: TINKER AFB, OKLAHOMA
Project Number: 409832

MONITORING WELL 2-63B

DRILLING AND SAMPLING INFORMATION

Boring Location: EAST OF FIRE TRAINING AREA
SURFACE ELEV.(FT): 1243.284
TOTAL DEPTH(FT.): 29.0
Logged By: K. KIRSCHENMANN
Date Started: 11/8/93
Drilled By: P. GUERREIN GEOTECHNOLOGY, INC.
Date Completed: 11/8/93
Drill Rig Type: CME-75
Drilling Method: 8" HOLLOW STEM AUGER

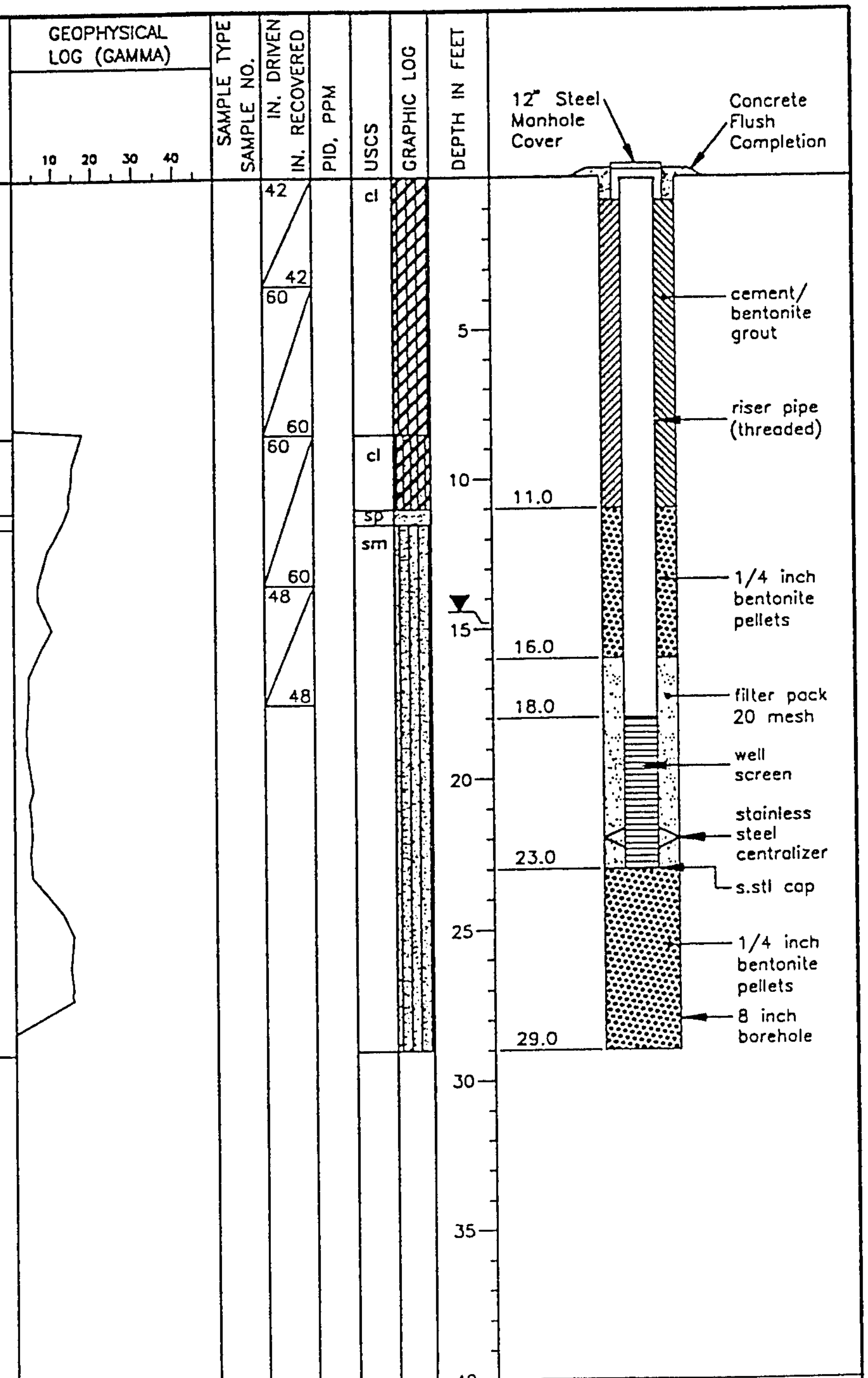
Sampling Method: 3"x5' CONTINUOUS SAMPLER

Notes: N 150386.113, E 2182035.358

WELL COMPLETION DATA

Elev-Top of Casing(ft.): Ref. Datum: MSL
1. Riser Pipe-I.D.(in.): 2 Depth(ft.): 18 Type: S.Steel
   Centralizers-Type: Depths(ft.):
2. Screen Dia.(in.): 2 Type: S.Steel Millslotted
   Depth Interval(ft.): 18-23 Slot Size(in.): .010
   Centralizers-Type: S.Steel Depths(ft.): 22
3. Filter Pack Type: Silica Sand Depth Interval(ft.): 16-23
   Conc. Pad Size: 4'x4'x6"

DESCRIPTION	IN. DRIVEN / IN. RECOVERED	USCS
SILTY CLAY - slightly plastic; <10% very fine grained sand; stiff; slightly moist; dark brown (7.5YR-3/4)	42 / 42	cl
- <5% to 10% very fine grained sand; dark red (2.5YR-4/8); gradational contact	60 / 60	
- nonplastic; hard; dry		
SANDY SILTY CLAY - nonplastic; 10% to 20% fine grained sand; hard; dry; dark red (2.5YR-4/8); gradational contact	60 / 60	cl
SAND - very fine grained; compact; dry; pale yellow (2.5YR-8/2); sharp contact		sp
SILTY SAND - 40% clay and silt; 50% to 60% fine to very fine grained sand; firm; dry; dark red (2.5YR-4/8); sharp contact - 60% fine to medium grained sand; slightly moist; gradational contact - alternating layers of siltstone and silty sand at 15' - moist - drill without sampling due to auger refusal	48 / 48	sm
TOTAL DEPTH = 29.0 FEET		



DRAFT BY	RPS 12/2/93	DRAFT CHK		PROJ. CHK		APPRV. BY		DWG. NO.	409832-A33 Sheet 1 of 1

Client: TINKER AFB
Project Name: TINKER 5001
Project Location: TINKER AFB, OKLAHOMA
Project Number: 409832

MONITORING WELL 2-64B

DRILLING AND SAMPLING INFORMATION

Boring Location: NORTHEAST OF FIRE TRAINING AREA
SURFACE ELEV.(FT): 1245.586
TOTAL DEPTH(FT.): 33.0
Logged By: K. KIRSCHENMANN
Date Started: 11/9/93
Drilled By: P. GUERREIN GEOTECHNOLOGY, INC.
Date Completed: 11/9/93
Drill Rig Type: CME-75
Drilling Method: 8" HOLLOW STEM AUGER

Sampling Method: 3"x5' CONTINUOUS SAMPLER

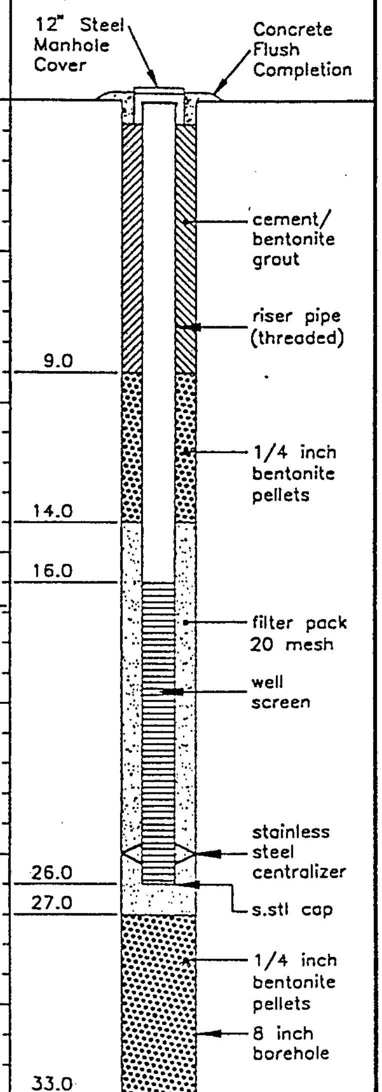
Notes: N 150467.403, E 2181967.757

WELL COMPLETION DATA

Elev-Top of Casing(ft.):
Ref. Datum: MSL

1. Riser Pipe-I.D.(in.): 2 Depth(ft.): 16 Type: S.Steel
   Centralizers-Type: Depths(ft.):
2. Screen Dia.(in.): 2 Type: S.Steel Millslotted
   Depth Interval(ft.): 16-26 Slot Size(in.): .010
   Centralizers-Type: S.Steel Depths(ft.): 25
3. Filter Pack Type: Silica Sand Depth Interval(ft.): 14-27
   Conc. Pad Size: 4'x4'x6"

DESCRIPTION	GEOPHYSICAL LOG (GAMMA) 10 20 30 40	SAMPLE TYPE / SAMPLE NO.	IN. DRIVEN / IN. RECOVERED	PID, PPM	USCS	GRAPHIC LOG	DEPTH IN FEET
SILTY CLAY - slightly plastic; <10% very fine grained sand; stiff; slightly moist; dark brown (7.5YR-3/3)			42 / 42	0	cl		0
- firm; dark red (2.5YR-4/6); gradational contact							
- very hard			60 / 60				5
- nonplastic; dark red (2.5YR-4/8); dry			60 / 60	0			10
			60 / 60	0			
SILTY CLAYEY SAND - 10% silt and clay, 80% to 90% very fine grained sand; firm; dry; pale yellow (2.5Y-7/3); sharp contact				0	sm-sc		15
- 10% to 20% silt and clay, 70% to 80% very fine grained sand; compact; dark red (2.5YR-4/8) at 15.5'							
- alternating siltstone and sand (16'-18.5')					sm		
- auger refusal at 18.5'							20
SILTY SAND							
- very rocky, hard layer; wet							25
							30
TOTAL DEPTH = 33.0 FEET							35
							40



DRAFT BY	RPS 12/3/93	DRAFT CHK		PROJ. CHK		APPRV. BY		DWG. NO.	409832-A34 Sheet 1 of 1

Client: TINKER AFB
Project Name: TINKER 5001

Project Location: TINKER AFB, OKLAHOMA
Project Number: 409832

MONITORING WELL 2-65B

DRILLING AND SAMPLING INFORMATION

Boring Location: NORTHEAST OF FIRE TRAINING AREA
SURFACE ELEV.(FT): 1250.812
TOTAL DEPTH(FT.): 49.0
Logged By: K. KIRSCHENMANN
Date Started: 11/5/93
Drilled By: P. GUERREIN GEOTECHNOLOGY, INC.
Date Completed: 11/5/93
Drill Rig Type: CME-75
Drilling Method: 8" HOLLOW STEM AUGER

Sampling Method: 3"x5' CONTINUOUS SAMPLER

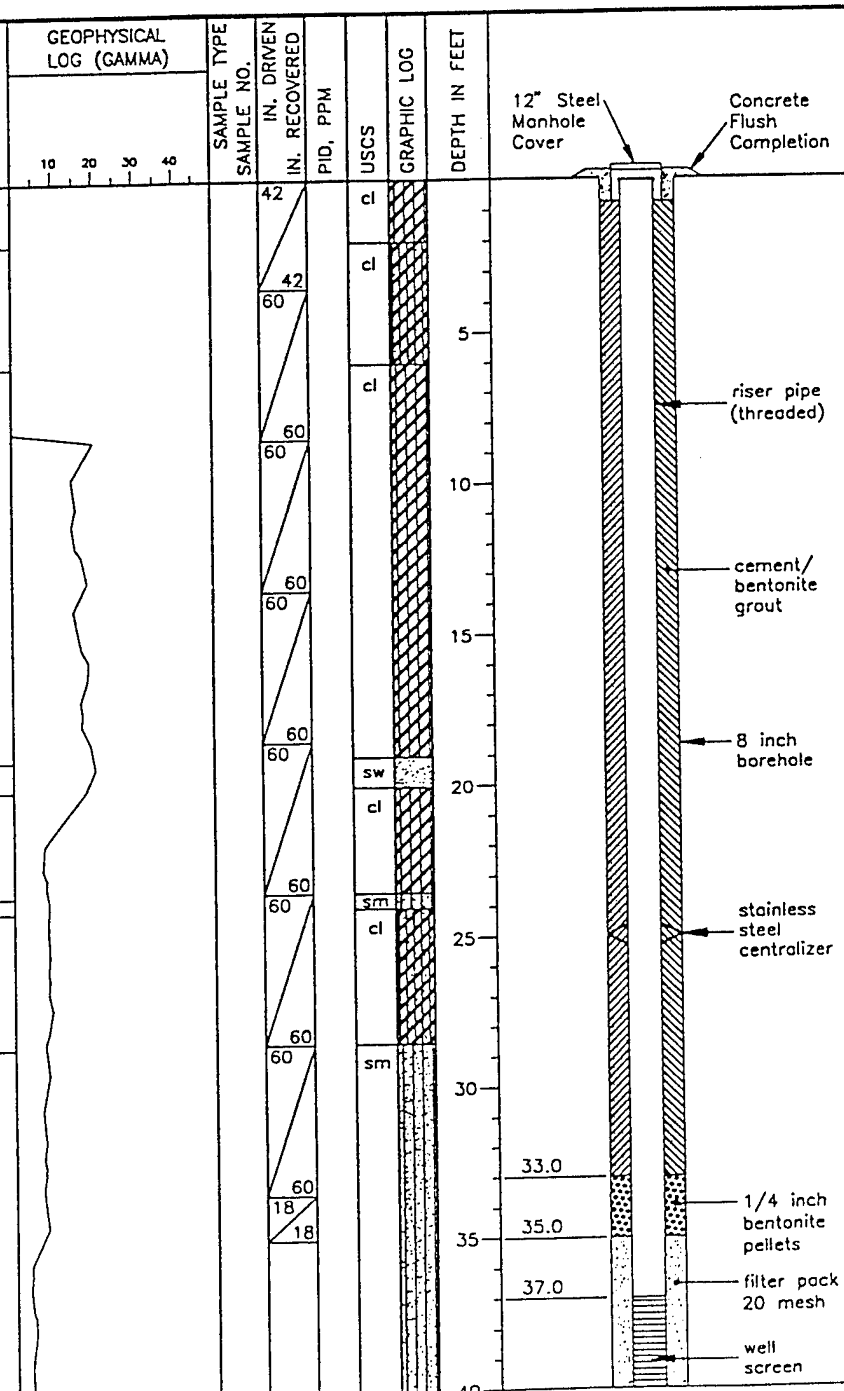
Notes: NO ANALYTICAL SAMPLES TAKEN
N 150712.875, E 2182183.201

WELL COMPLETION DATA

Elev-Top of Casing(ft.):
Ref. Datum: MSL

1. Riser Pipe-I.D.(in.): 2 — Depth(ft.): 37 — Type: S.Steel
   Centralizers-Type: S.Steel — Depths(ft.): 25
2. Screen Dia.(in.): 2 — Type: S.Steel Millslotted
   Depth Interval(ft.): 37-47 — Slot Size(in.): .010
   Centralizers-Type: S.Steel — Depths(ft.): 46
3. Filter Pack Type: Silica Sand — Depth Interval(ft.): 35-49
   Conc. Pad Size: 4'x4'x6"

DESCRIPTION	IN. DRIVEN / IN. RECOVERED	USCS
SILTY CLAY - slightly plastic; <5% very fine grained sand; stiff; slightly moist; dark brown (7.5YR-3/4); organic rich	42 / 42	cl
SILTY SANDY CLAY - slightly plastic; 10% fine grained sand; hard; slightly moist; dark red (2.5YR-4/6); gradational contact - black nodules	60 / 60	cl
SILTY CLAY - nonplastic; hard; dry; dark red (2.5YR-4/8); gradational contact	60 / 60; 60 / 60; 60 / 60	cl
SAND - very fine to fine grained; compact; slightly moist; pale yellow (2.5Y-8/2); sharp contact	60 / 60	sw
SILTY CLAY - nonplastic; very hard; dry; dark red (2.5YR-4/6); sharp contact		cl
SILTY SAND - 30% silt and clay, 70% fine grained sand; compact; dry; dark red (2.5YR-4/6); gradational contact	60 / 60	sm
SANDY SILTY CLAY - nonplastic; 10% to 25% very fine to fine grained sand; stiff; dry; dark red (2.5YR-4/6); sharp contact		cl
SILTY SAND - 50% silt and clay, 50% fine grained sand; firm; dry; dark red (2.5YR-4/6); gradational contact	60 / 60; 18 / 18	sm



DRAFT BY	RPS 12/9/93	DRAFT CHK		PROJ. CHK		APPRV. BY		DWG. NO.	409832-A35 Sheet 1 of 2

Client: TINKER AFB
Project Name: TINKER 5001

Project Location: TINKER AFB, OKLAHOMA
Project Number: 409832

MONITORING WELL 2-65B

DRILLING AND SAMPLING INFORMATION

Boring Location: NORTHEAST OF FIRE TRAINING AREA
SURFACE ELEV.(FT): 1250.812
TOTAL DEPTH(FT.): 49.0
Logged By: K. KIRSCHENMANN
Date Started: 11/5/93
Drilled By: P. GUERREIN GEOTECHNOLOGY, INC.
Date Completed: 11/5/93
Drill Rig Type: CME-75
Drilling Method: 8" HOLLOW STEM AUGER

Sampling Method: 3"x5' CONTINUOUS SAMPLER

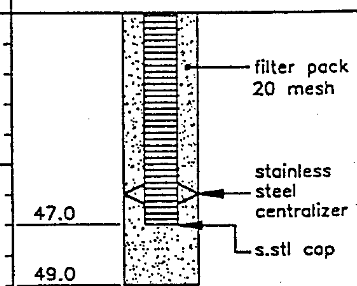
Notes: NO ANALYTICAL SAMPLES TAKEN
N 150712.875, E 2182183.201

WELL COMPLETION DATA

Elev-Top of Casing(ft.):
Ref. Datum: MSL

1. Riser Pipe-I.D.(in.): 2 Depth(ft.): 37 Type:S.Steel
   Centralizers-Type: S.Steel Depths(ft.): 25
2. Screen Dia.(in.): 2 Type: S.Steel Millslotted
   Depth Interval(ft.): 37-47 Slot Size(in.): .010
   Centralizers-Type: S.Steel Depths(ft.): 46
3. Filter Pack Type: Silica Sand Depth Interval(ft.): 35-49
   Conc. Pad Size: 4'x4'x6"

DESCRIPTION	GEOPHYSICAL LOG (GAMMA) 10 20 30 40	SAMPLE TYPE	SAMPLE NO.	IN. DRIVEN	IN. RECOVERED	PID, PPM	USCS	GRAPHIC LOG	DEPTH IN FEET
TOTAL DEPTH = 49.0 FEET									45, 50, 55, 60, 65, 70, 75, 80



DRAFT BY	RPS 12/9/93	DRAFT CHK		PROJ. CHK		APPRV. BY		DWG. NO.	409832-A35 Sheet 2 of 2

SITE FTA2 BORING NUMBER 2-167B

PROJECT TAFB Phase II RFI App. I Sites, Fire Train. Area 2
DATE DRILLED 07 August 1995 (Drilled as MW1)
DRILLING METHOD 6" Hollow-stem Augers; 5' Continuous Sampler
DRILLING COMPANY Associated Environmental Industries
ELEVATION 1247.70 Feet msl, Ground Surface; 1,250.74 Feet msl, TOC
TOTAL DEPTH 32 Feet
DEPTH TO WATER 14.8 Feet (open hole)
GEOLOGIST R. Osgood
X,Y COORD. 2182408.352, 150539.8117

DEPTH feet	PID (ppm)	MUNSELL	LITHOLOGY	DESCRIPTION AND REMARKS
0			OL	Topsoil, silty, w/vegetation and subrounded, pebble-sized clasts.
	ND	2.5YR4/4	ML CL	Clayey silt, reddisg brown, soft, slightly moist, low plasticity, some black organic speckling throughout.
	ND	2.5YR4/6		At 4 ft, grades to silt, red, firm, dry, a few small subrounded pebbles; light grey marbling at base.
5	ND			Clayey silt, reddish brown, firm, dry, some black organic speckling, and trace of light grey marbling (mineralization?).
	ND	2.5YR4/4		
10	ND	2.5YR4/6		Clayey silt, red, firm, dry, massive (homogeneous).
				No Recovery
15	ND	2.5YR4/6	ML	Silt, light grey, stiff, moist for top 1", Interval grades from silt to sandy silt, red, moist, soft, massive. At 12 ft, moderately cemented sandstone clasts appx. 1" in diameter.
	ND			
				No Recovery
20	ND	2.5YR4/6	ML	Sandy silt (appx 75% silt), red, soft, very moist, few 1" moderately cemented sandstone fragments; lens of fine sand appx. 1" thick at 21.5 ft.
	ND			
				No Recovery
25			SM	

SAMPLE: Analytical, Geotechnical, Interval, Recovery; GRAPHIC LOG

JOB NUMBER: Tetra Tech, Inc. TC-7107

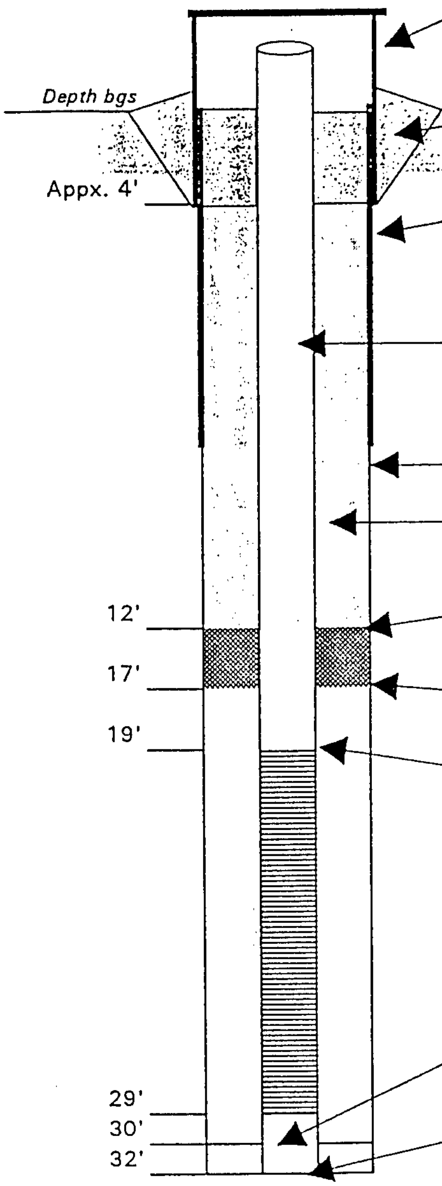
SITE FTA2 BORING NUMBER 2-167B

PROJECT: TAFB Phase II RFI App. I Sites, Fire Train. Area 2
DATE DRILLED: 07 August 1995 (Drilled as MW1)
DRILLING METHOD: 6" Hollow-stem Augers; 5' Continuous Sampler
DRILLING COMPANY: Associated Environmental Industries
ELEVATION: 1247.70 Feet msl, Ground Surface; 1,250.74 Feet msl, TOC
TOTAL DEPTH: 32 Feet
DEPTH TO WATER: 14.8 Feet (open hole)
GEOLOGIST: R. Osgood
X,Y COORD.: 2182408.352, 150539.8117

SAMPLE: Analytical	SAMPLE: Geotechnical	SAMPLE: Interval	SAMPLE: Recovery	DEPTH feet	PID (ppm)	MUNSELL	LITHOLOGY	GRAPHIC LOG	DESCRIPTION AND REMARKS
					ND	2.5YR4/4	SM		Silty sand (60%), reddish brown, soft, wet, very fine sand laminated throughout.
									No Recovery
				30			SP		Sand, red, fine grained, poorly graded, wet, homogeneous color and massive texture.
									Completed as monitoring well 2-187 on 07 August 1995.
				35					
				40					
				45					
				50					

Tetra Tech Monitoring Well Construction Log

Project/Site Name: TAFB Phase II RFI, FTA2	Well No: 2-167 B	Date: 08 Aug 95	
Project No: 7107	Drilling Method: 8-3/4" Hollow-stem Augers		
Geologist: R. Osgood			
Elevation of Casing: 1250.7 Ft msl	Drilling Contractor: Associated Environmental Industries		
Surface Elevation: 1247.7 Ft msl	Date Well Construction Completed: 08 Aug 95		



Type of Protective Casing: Steel
Dimensions: 6"x6"x60"
Height of Stickup: 2.8 ft
Weep Hole: Y/N Cap Vent: Y/N Locking Cap: Y/N

Type of Surface Grout: Concrete to appx. 4 ft bgs.

Surface Casing(s) Diameter/Type/Length:
Not Applicable
Surface Casing Grouting Information:
Not Applicable

Riser Length Above Screen: 21.8 ft
Riser Inner Diameter/Type: 4" diameter
Schedule 304 Stainless Steel

Boring Diameter(s): 8-3/4"

Type of Annular Seal: Portland Type I, 2% Bentonite

Depth to Bentonite Seal: 12 ft
Type of Bentonite: Medium Chips
Length of Seal: 5 ft

Depth to Top of Filter Pack: 17 ft
Type of Filter Pack: 10/20 Sand

Depth to Screen: 19 ft
Screen Length and Type: 10 ft, 4" diameter
Schedule 304 Stainless Steel
Slot Size: 0.010"
Screened Interval: 19 to 29 ft

Length of Sediment Sump: 3 ft
Diameter/Type of Sediment Sump:
4" diameter Sch. 304 Stainless Steel

Original Boring Depth: 32 ft
Top of Bentonite Plug: 30 ft
Type of Backfill: Bentonite Chips

Centralizers: At appx. 18 ft and 30 ft.

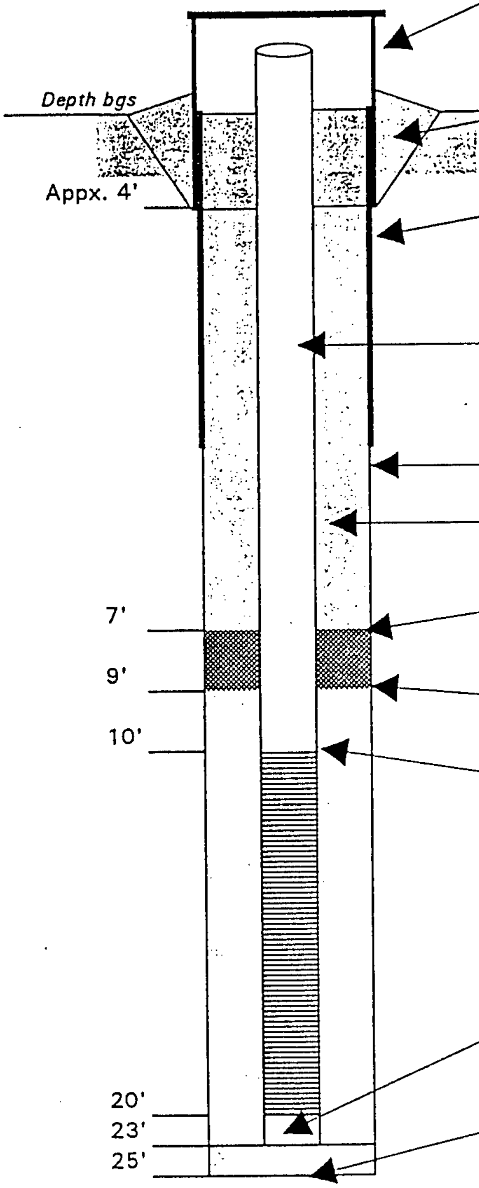
SITE FTA2 BORING NUMBER 2-168B

PROJECT: TAFB Phase II RFI App. I Sites, Fire Train. Area 2
DATE DRILLED: 08 August 1995 (Drilled as MW2)
DRILLING METHOD: 6" Hollow-stem Augers; 5' Continuous Sampler
DRILLING COMPANY: Associated Environmental Industries
ELEVATION: 1240.10 Feet msl, Ground Surface; 1,243.00 Feet msl, TOC
TOTAL DEPTH: 25 Feet
DEPTH TO WATER: 10.6 Feet bgs
GEOLOGIST: R. Osgood
X,Y COORD.: 2181976.691, 150248.99500

DEPTH feet	PID (ppm)	MUNSELL	LITHOLOGY	DESCRIPTION AND REMARKS
0–5	ND, 15, ND	2.5YR3/4	ML CL	Topsoil, clayey silt, dark reddish brown, soft, slightly moist, root hairs extend to 1.5 ft. Clayey silt stiffens to base of core with trace of organic speckling from 2 to 5 ft.
5–10	1.0, ND	2.5YR4/4	ML CL	Clayey silt, reddish brown, soft to firm, slightly moist, massive, some black organic speckling and small nodules. Form 7 to 10 ft, some subangular pebbles and increase in the amount of black organics.
10	ND		ML CL	Clayey silt as above to 10.8 ft.
10.8–13	21, 4/6	2.5YR4/4, 2.5YR4/6	ML	Sandy silt, red, soft, moist to saturated at 13 ft, thin bedding (laminated), black organics from 11.5 to 12 ft.
13–15				No Recovery
15–19	20, 3, 1	2.5YR4/6	SM	Silty sand, red, wet, laminated layers (2-5 mm). From 17 to 17.5 ft, dark black organic lens with small (<3 mm) nodules. Some black speckles of organic matter to 19 ft.
19–20				No Recovery
20–22	21	2.5YR4/6	SM	Silty sand, red, wet, laminated (appx. 2 mm), trace of black organic speckling throughout.
22–25				No Recovery

Tetra Tech Monitoring Well Construction Log

Project/Site Name:	TAFB Phase II RFI, FTA2	Well No: 2-168 B	Date: 08 Aug 95
Project No:	7107	Drilling Method:	8-3/4" Hollow-stem Augers
Geologist:	R. Osgood		
Elevation of Casing:	1243.0 Ft msl	Drilling Contractor:	Associated Environmental Industries
Surface Elevation:	1240.1 Ft msl	Date Well Construction Completed:	08 Aug 95



Type of Protective Casing: Steel
Dimensions: 6"x6"x60"
Height of Stickup: 2.8 ft
Weep Hole: Y/N Cap Vent: Y/N Locking Cap: Y/N

Type of Surface Grout: Concrete to appx. 4 ft bgs

Surface Casing(s) Diameter/Type/Length:
Not Applicable
Surface Casing Grouting Information:
Not Applicable

Riser Length Above Screen: 12.8 ft
Riser Inner Diameter/Type: 4" diameter
Schedule 304 Stainless Steel

Boring Diameter(s): 8-3/4"

Type of Annular Seal: Portland Type I, 2% Bentonite

Depth to Bentonite Seal: 7 ft
Type of Bentonite: Medium Chips
Length of Seal: 2 ft

Depth to Top of Filter Pack: 9 ft
Type of Filter Pack: 10/20 Sand

Depth to Screen: 10 ft
Screen Length and Type: 10 ft, 4" diameter
Schedule 304 Stainless Steel
Slot Size: 0.010"
Screened Interval: 10 to 20 ft

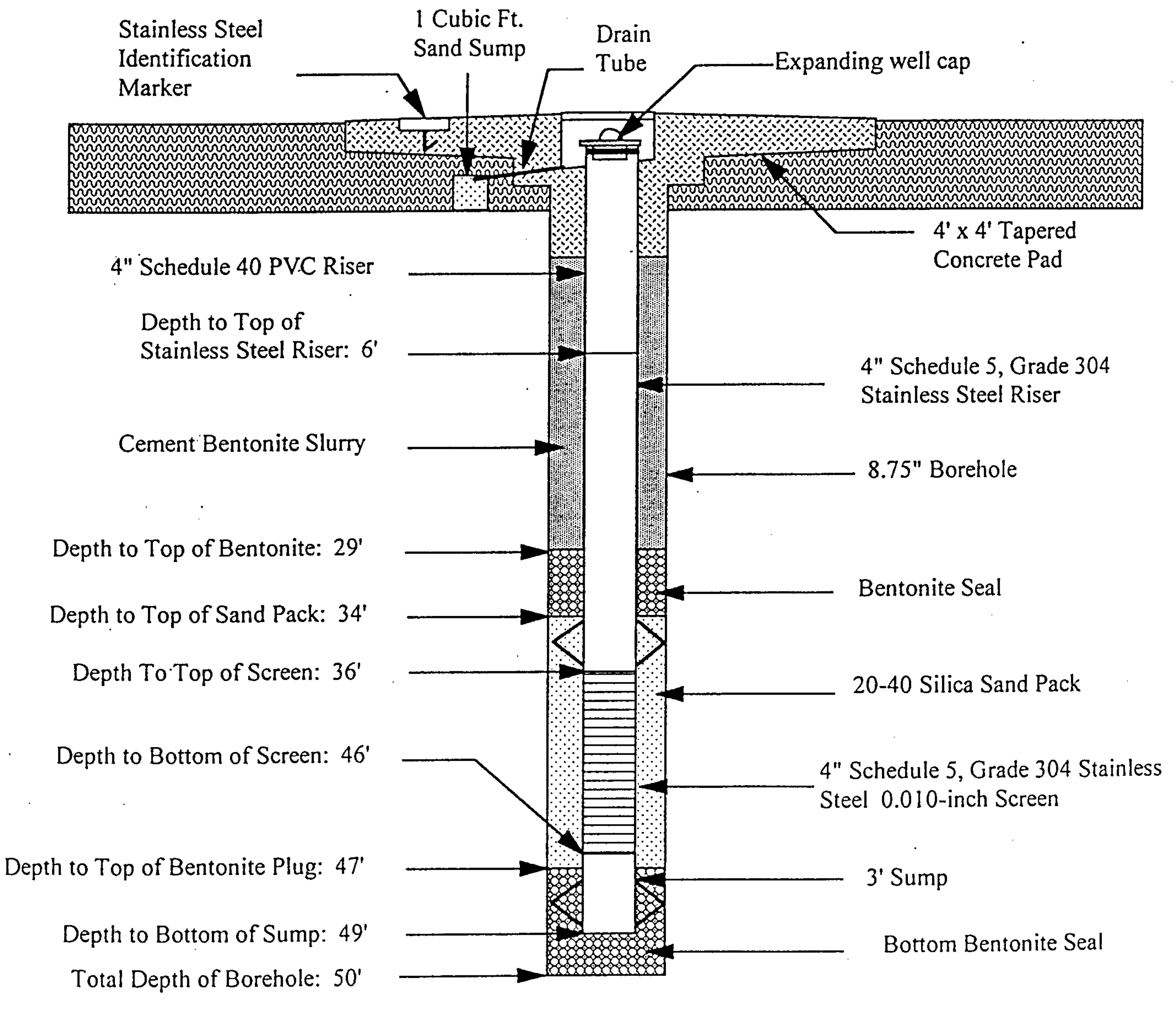
Length of Sediment Sump: 3 ft
Diameter/Type of Sediment Sump:
4" diameter Sch. 304 Stainless Steel

Original Boring Depth: 25 ft
Top of Bentonite Plug: 23 ft
Type of Backfill: Bentonite Chips

Centralizers: At appx. 9.5 ft and 21.5 ft

WELL CONSTRUCTION SCHEMATIC

Client: Tinker Air Force Base	Well ID: 2-271B
Location: TAFB, Oklahoma	Site: FT22
Contract No: F34650-94-D-0082/5017 (P&A #4)	Date 4-Inch Riser Set: 08/08/96
Contractor: Brown & Root Environmental	Ground Level Elevation (AMSL): 1,252.41'
Project Manager: David Parker	Top of Casing Elevation (AMSL): 1,252.13'
Project Geologist: Steve Kelly	Northing Coordinate: 151,494.42'
Drilling Contractor: Associated Environmental, Inc.	Easting Coordinate: 2,182,196.43'
Drilling Method: Hollow Stem Auger	Permanent Monuments Used in Survey: SE32, SE28
Dedicated Pump: 2-inch Grundfos	Legal Description: NE/4 Section 22, T11N, R2W
Comments:	



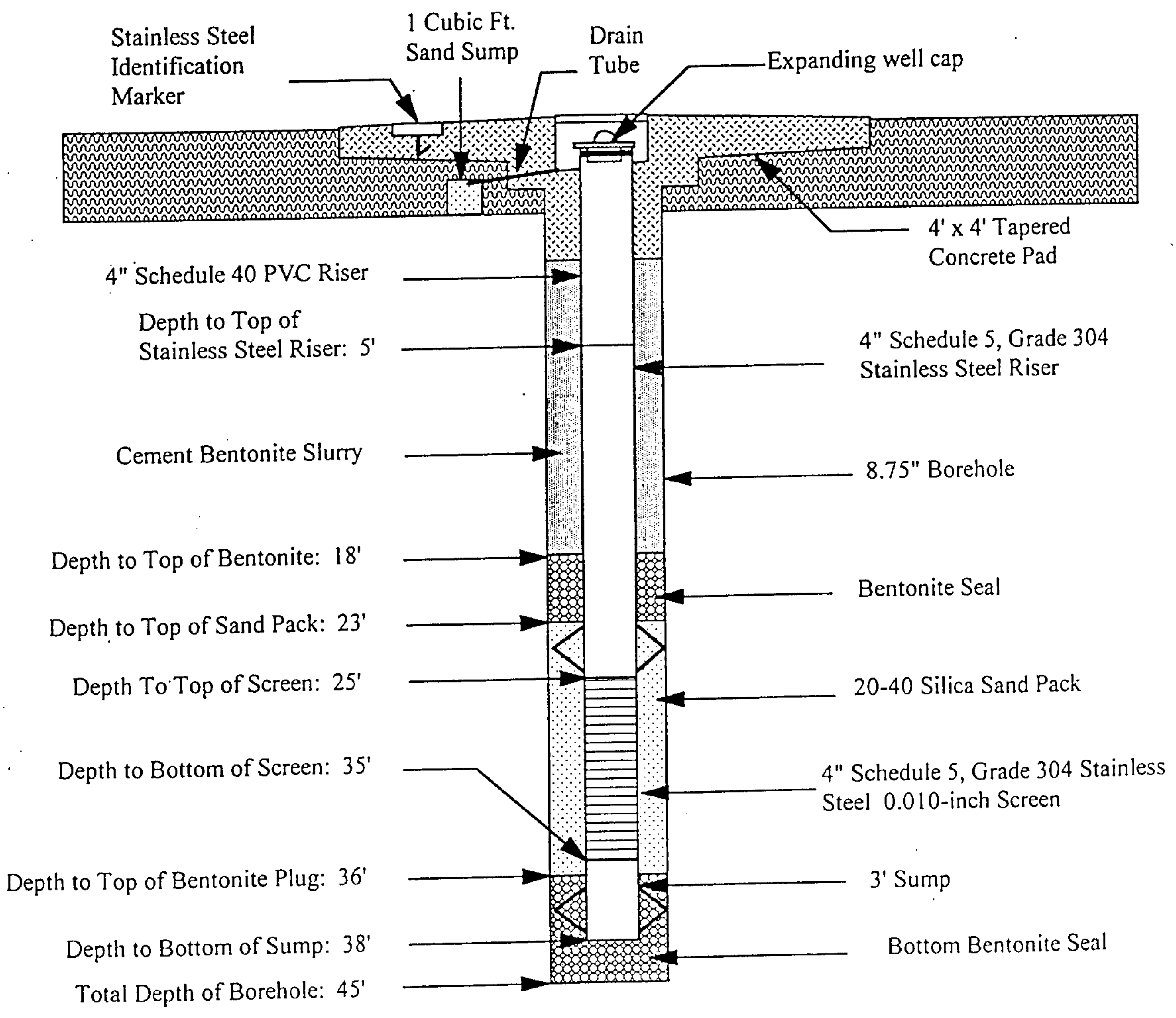
Drawing not to scale

< > Centralizers

WELL CONSTRUCTION SCHEMATIC

Client: Tinker Air Force Base	Well ID: 2-272B
Location: TAFB, Oklahoma	Site: FT22
Contract No: F34650-94-D-0082/5017 (P&A #4)	Date 4-Inch Riser Set: 08/09/96
Contractor: Brown & Root Environmental	Ground Level Elevation (AMSL): 1,249.38'
Project Manager: David Parker	Top of Casing Elevation (AMSL): 1,248.91'
Project Geologist: Steve Kelly	Northing Coordinate: 150,784.70'
Drilling Contractor: Associated Environmental, Inc.	Easting Coordinate: 2,181,581.74'
Drilling Method: Hollow Stem Auger	Permanent Monuments Used in Survey: SE32, SE28
Dedicated Pump: 2-inch Grundfos	Legal Description: SE/4 Section 22, T11N, R2W

Comments: Ground Level Elevation measured on identification plate rather than surveyor's pin.



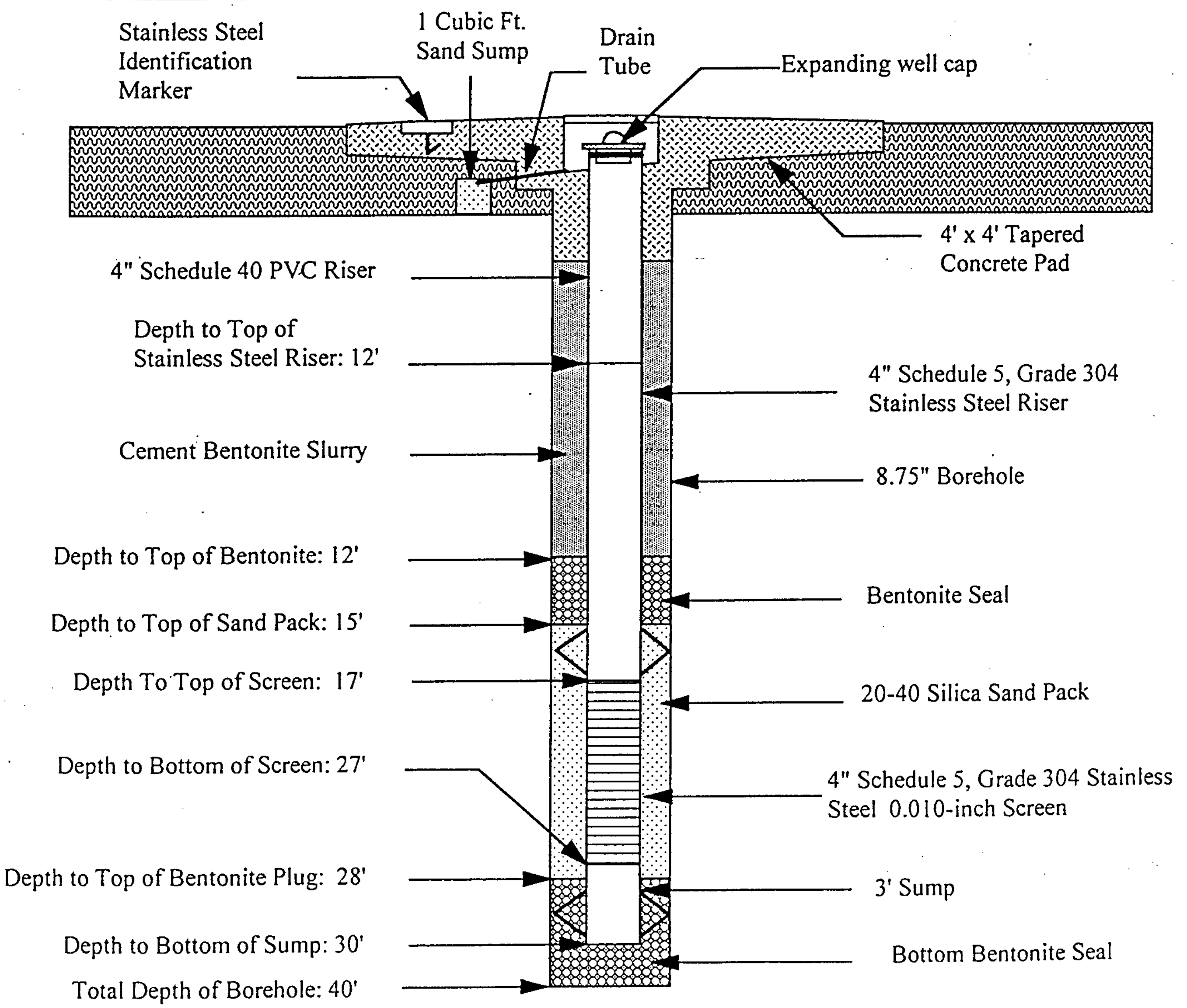
Drawing not to scale

< > Centralizers

WELL CONSTRUCTION SCHEMATIC

Client: Tinker Air Force Base	Well ID: **2-273B**
Location: TAFB, Oklahoma	Site: FT22
Contract No: F34650-94-D-0082/5017 (P&A #4)	Date 4-Inch Riser Set: 06/18/96
Contractor: Brown & Root Environmental	Ground Level Elevation (AMSL): 1,238.92'
Project Manager: David Parker	Top of Casing Elevation (AMSL): 1,238.42'
Project Geologist: Steve Kelly	Northing Coordinate: 150,351.11'
Drilling Contractor: Associated Environmental, Inc.	Easting Coordinate: 2,181,576.36'
Drilling Method: Hollow Stem Auger	Permanent Monuments Used in Survey: SE32, SE28
Dedicated Pump: 2-inch Grundfos	Legal Description: SE/4 Section 22, T11N, R2W

Comments: Ground Level Elevation measured on identification plate rather than surveyor's pin. 3' thick top bentonite seal set.



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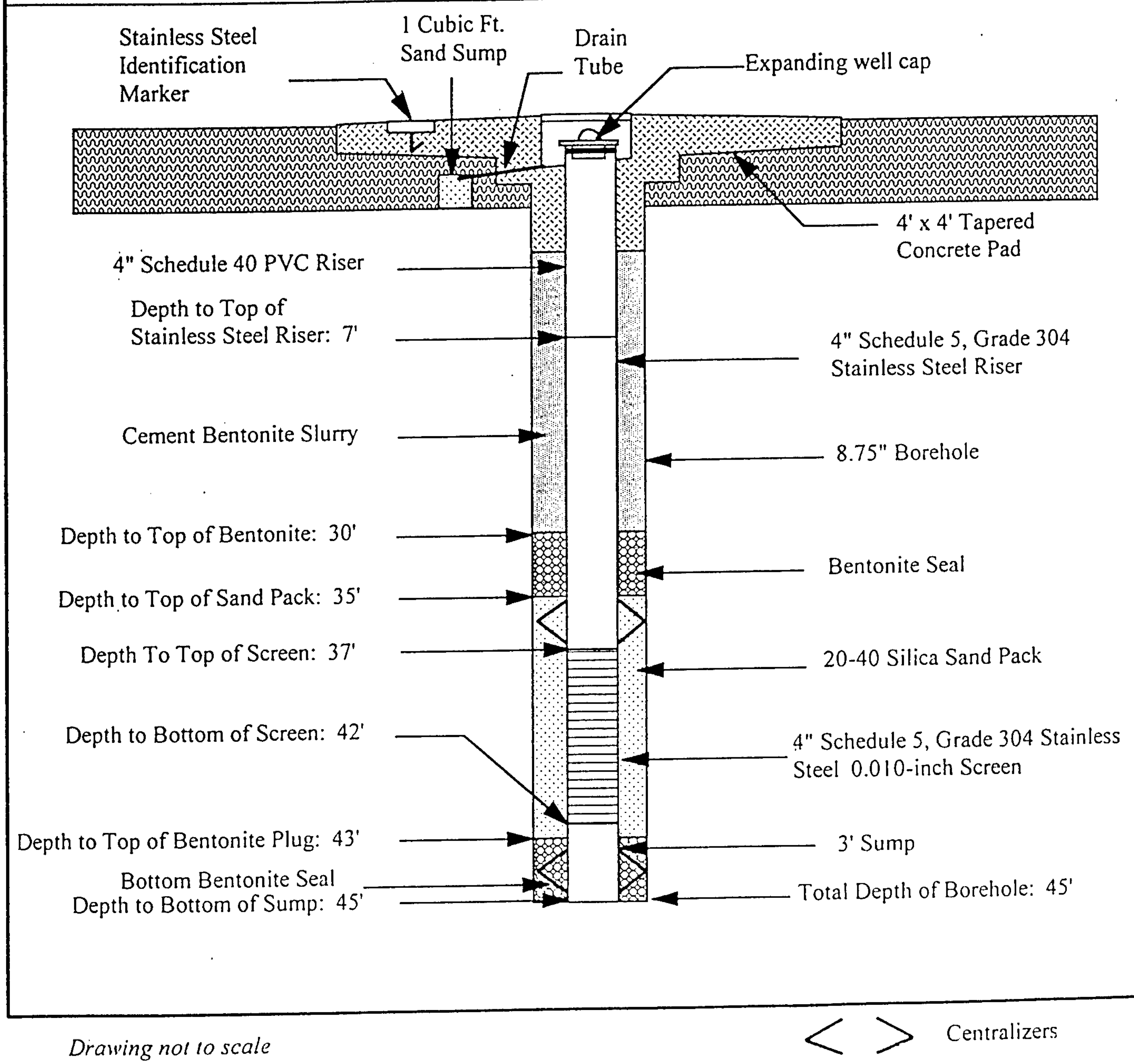
< > Centralizers

WELL CONSTRUCTION SCHEMATIC

Client: Tinker Air Force Base	Well ID: **2-274B**
Location: TAFB, Oklahoma	Site: FT22
Contract No: F34650-94-D-0082/5017 (P&A #4)	Date 4-Inch Riser Set: 07/25/96
Contractor: Brown & Root Environmental	Ground Level Elevation (AMSL): 1,248.77'
Project Manager: David Parker	Top of Casing Elevation (AMSL): 1,248.32'
Project Geologist: Steve Kelly	Northing Coordinate: 151,126.23'
Drilling Contractor: Associated Environmental, Inc.	Easting Coordinate: 2,181,625.92'
Drilling Method: Hollow Stem Auger	Permanent Monuments Used in Survey: SE32, SE28
Dedicated Pump: 2-inch Grundfos	Legal Description: NE/4 Section 22 T11N, R2W

Comments: 5' long screen set. Well set at bottom of borehole. Ground Level Elevation measured on identification plate rather than surveyor's pin.



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5/22/93

MW1-67B	RISER	0 - 34
	SCREEN	34 - 44
	SAND PACK	32 - 44
	BENTONITE	30 - 32
	GROUT	0 - 30

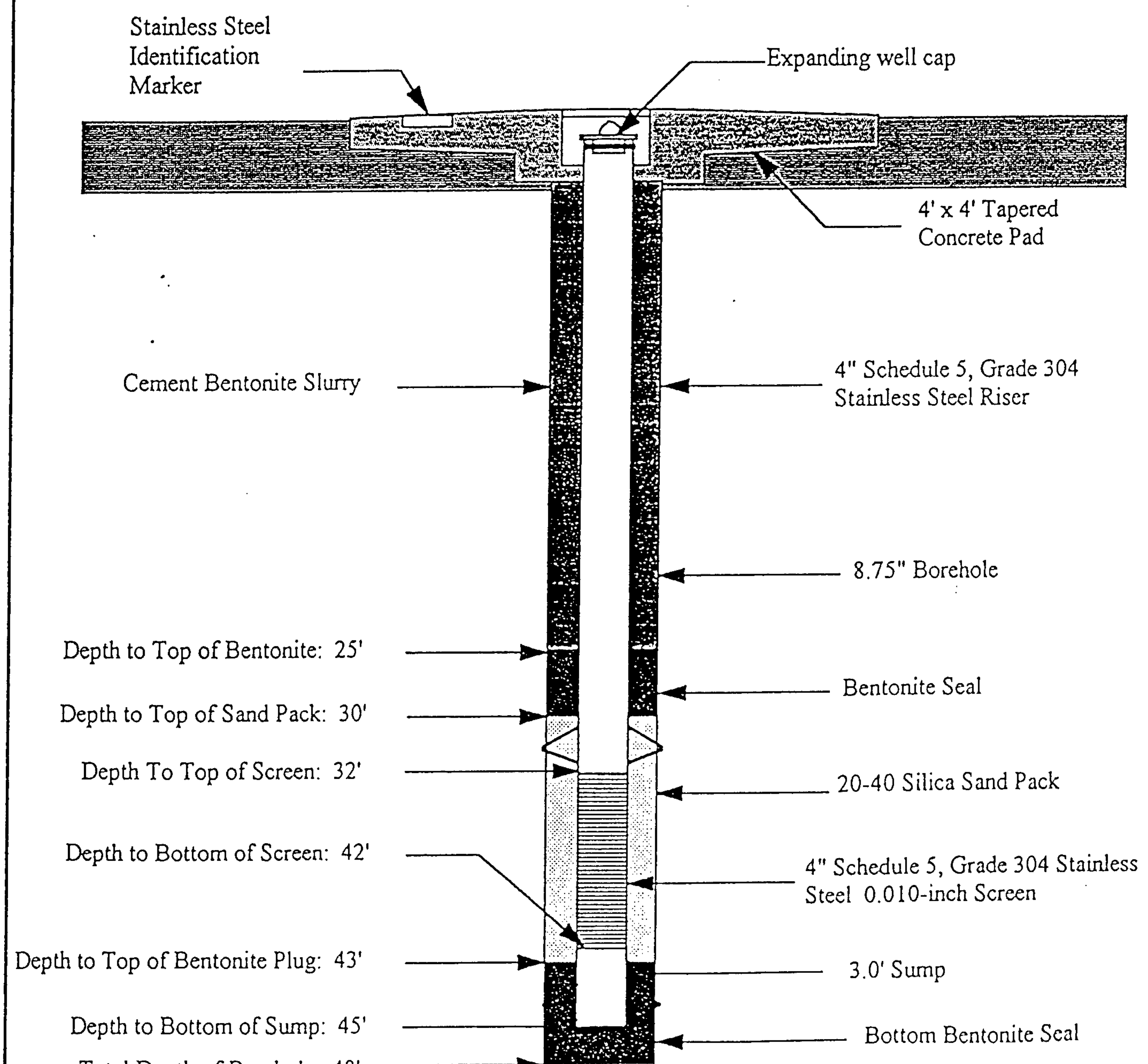
MW 1-67 A	10" SURFACE CASING	0 - 46
	RISER	0 - 75
	SCREEN	75 - 85
	SAND PACK	73 - 85
	BENTONITE	71 - 73
	GROUT	0 - 71

MW 1-67 C	16" SURFACE CASING	0 - 46
	10" CASING	0 - 90
	RISER	0 - 109
	SCREEN	109 - 119'
	SAND PACK	107 - 119
	BENTONITE	105 - 107
	GROUT	0 - 105

MW 1-67 WELL COMPLETION INFO.

WELL CONSTRUCTION SCHEMATIC

Client: Tinker Air Force Base	Well ID: **2-142B**
Location: TAFB, Oklahoma	Site: BW
Contract No: F34650-94-D-0082/5004 (P & A 3)	Date 4-Inch Riser Set: 05/19/95
Contractor: Brown & Root Environmental	Drilling Method: Mud Rotary
Project Manager: David Parker	Ground Level Elev. (AMSL): 1242.45'
Project Geologist: James W. Roberts	Top of Csg. Elev. (AMSL): 1242.09'
Drlg Contractor: Associated Environmental, Inc.	Dedicated Pump: 2-inch Grundfos
Comments: Top Riser: 4" Schedule 40 PVC Casing.	



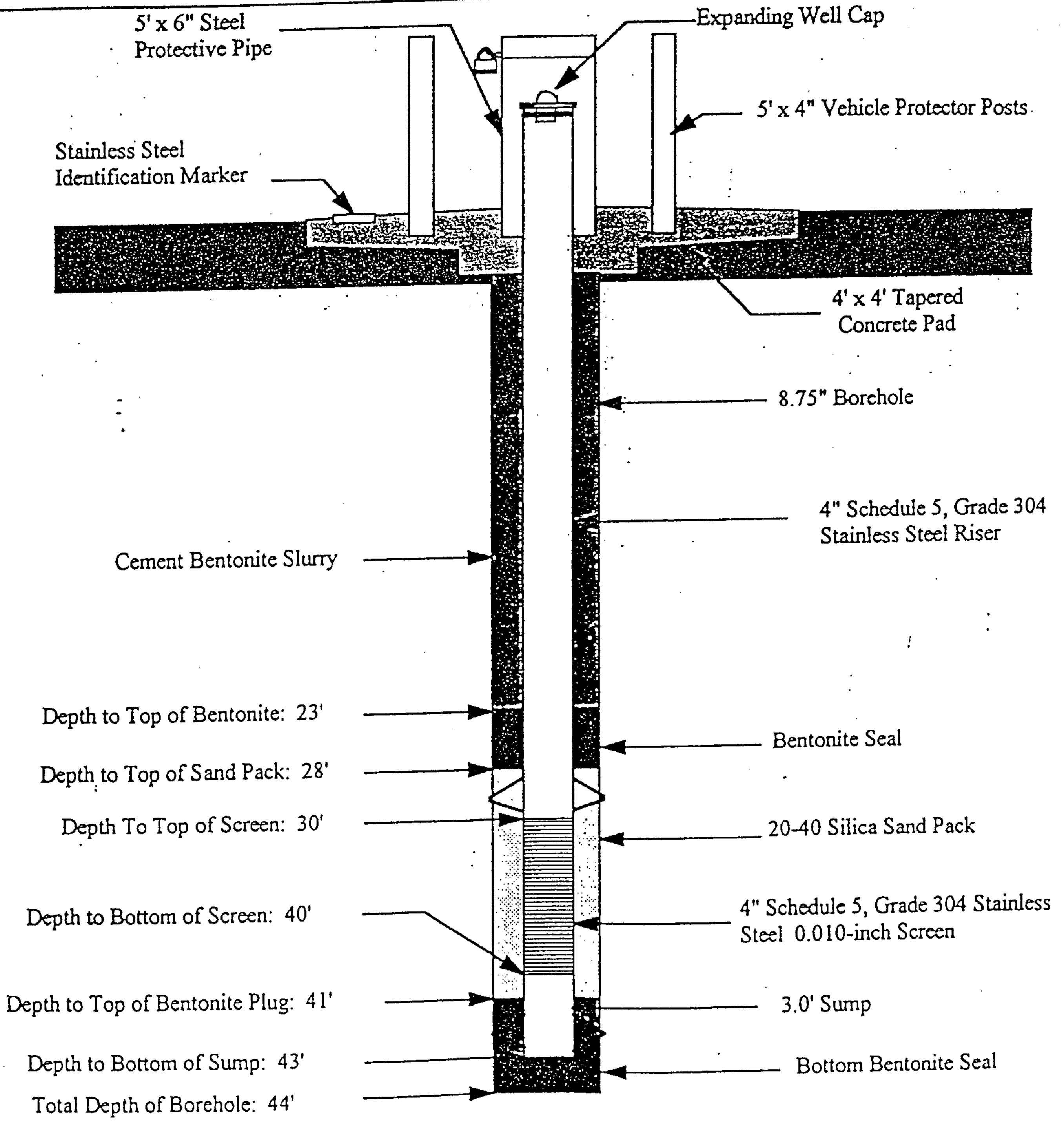
Drawing not to scale

< > Centralizers

WELL CONSTRUCTION SCHEMATIC

Client: Tinker Air Force Base	Well ID: 2-112B
Location: TAFB, Oklahoma	Site: LF15
Contract No: F34650-94-D-0082/5003 (P & A 2)	Date 4-Inch Riser Set: 1/20/95
Contractor: Brown & Root Environmental	Drilling Method: Auger
Project Manager: David Parker	Ground Level Elev. (AMSL): 1250.89'
Project Geologist: James W. Roberts	Top of Csg. Elev. (AMSL): 1247.65'
Drlg Contractor: Associated Environmental, Inc.	Dedicated Pump: 2-inch Grundfos

Comments: Top Riser : 4" Schedule 40 PVC Casing.

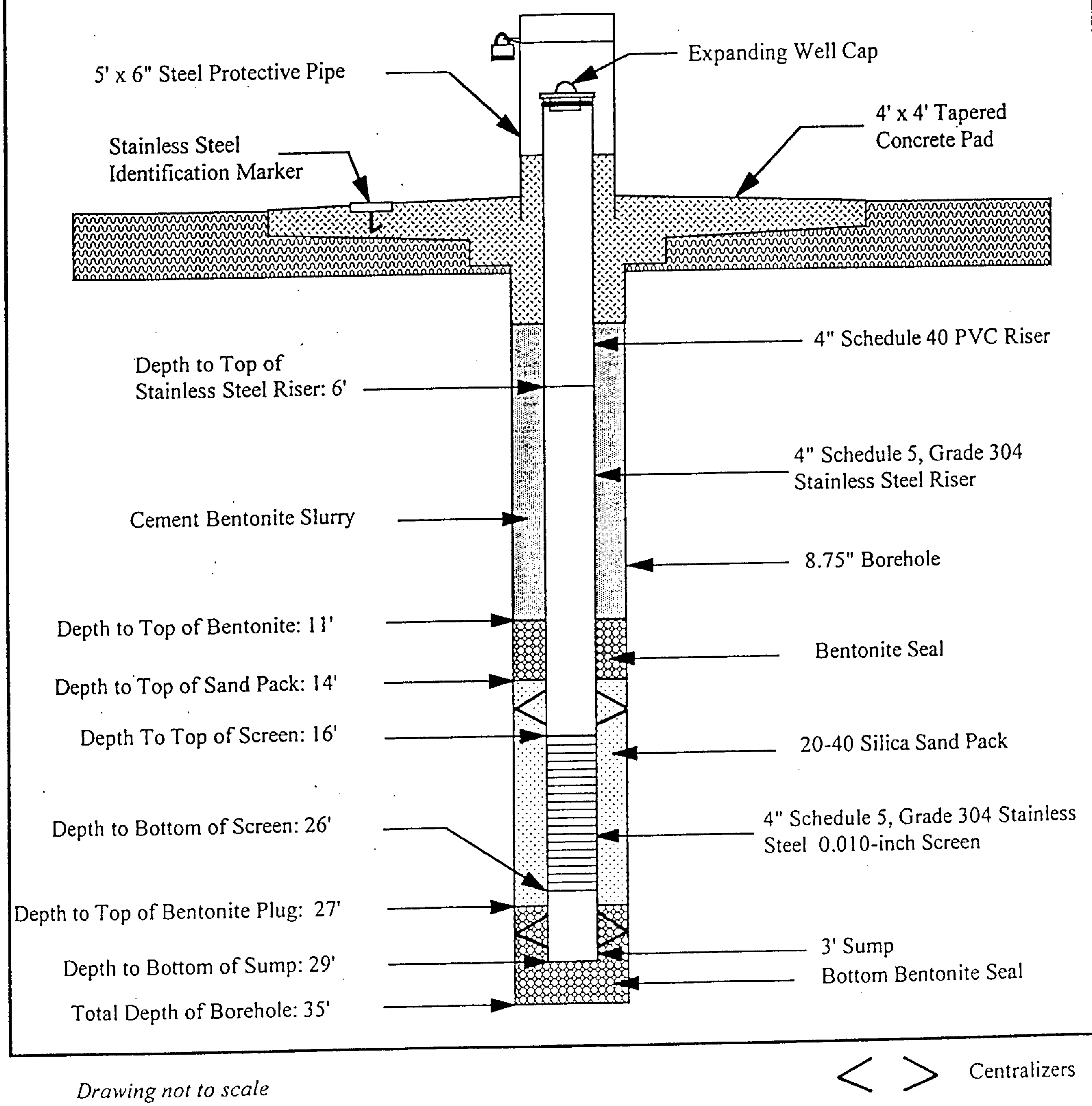


< > Centralizers

Drawing not to scale

WELL CONSTRUCTION SCHEMATIC

Client: Tinker Air Force Base	Well ID: **2-301B**
Location: TAFB, Oklahoma	Site: LF15
Contract No: F34650-94-D-0082/5017 (P&A #4)	Date 4-Inch Riser Set: 06/17/96
Contractor: Brown & Root Environmental	Ground Level Elevation (AMSL): 1,263.19'
Project Manager: David Parker	Top of Casing Elevation (AMSL): 1,265.71'
Project Geologist: Steve Kelly	Northing Coordinate: 150,500.39'
Drilling Contractor: Associated Environmental, Inc.	Easting Coordinate: 2,176,072.65'
Drilling Method: Hollow Stem Auger	Permanent Monuments used in Survey: SE40, PR15
Dedicated Pump: 2-inch Grundfos	Legal Description: SW/4 Section 23, T11N, R2W
Comments: 3' thick top bentonite seal set..	



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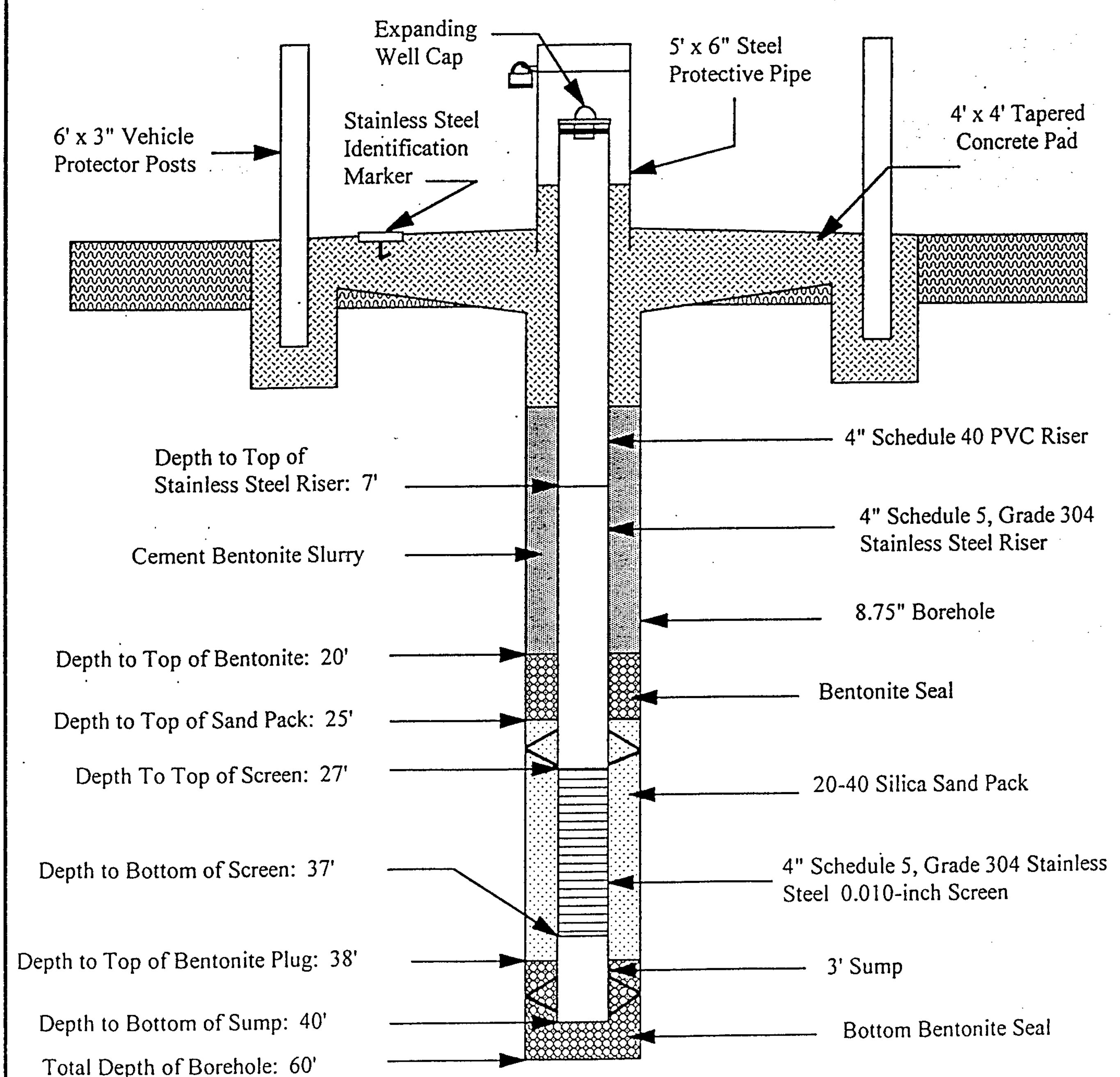
WELL CONSTRUCTION SCHEMATIC

Client: Tinker Air Force Base	Well ID: **2-302B**
Location: TAFB, Oklahoma	Site: LF15
Contract No: F34650-94-D-0082/5017 (P&A #4)	Date 4-Inch Riser Set: 07/24/96
Contractor: Brown & Root Environmental	Ground Level Elevation (AMSL): 1,246.46'
Project Manager: David Parker	Top of Casing Elevation (AMSL): 1,249.15'
Project Geologist: Steve Kelly	Northing Coordinate: 149,491.80'
Drilling Contractor: Associated Environmental, Inc.	Easting Coordinate: 2,182,106.79'
Drilling Method: Hollow Stem Auger	Permanent Monuments used in Survey: SE32, SE28
Dedicated Pump: 2-inch Grundfos	Legal Description: SE/4 Section 22, T11N, R2W
Comments:	



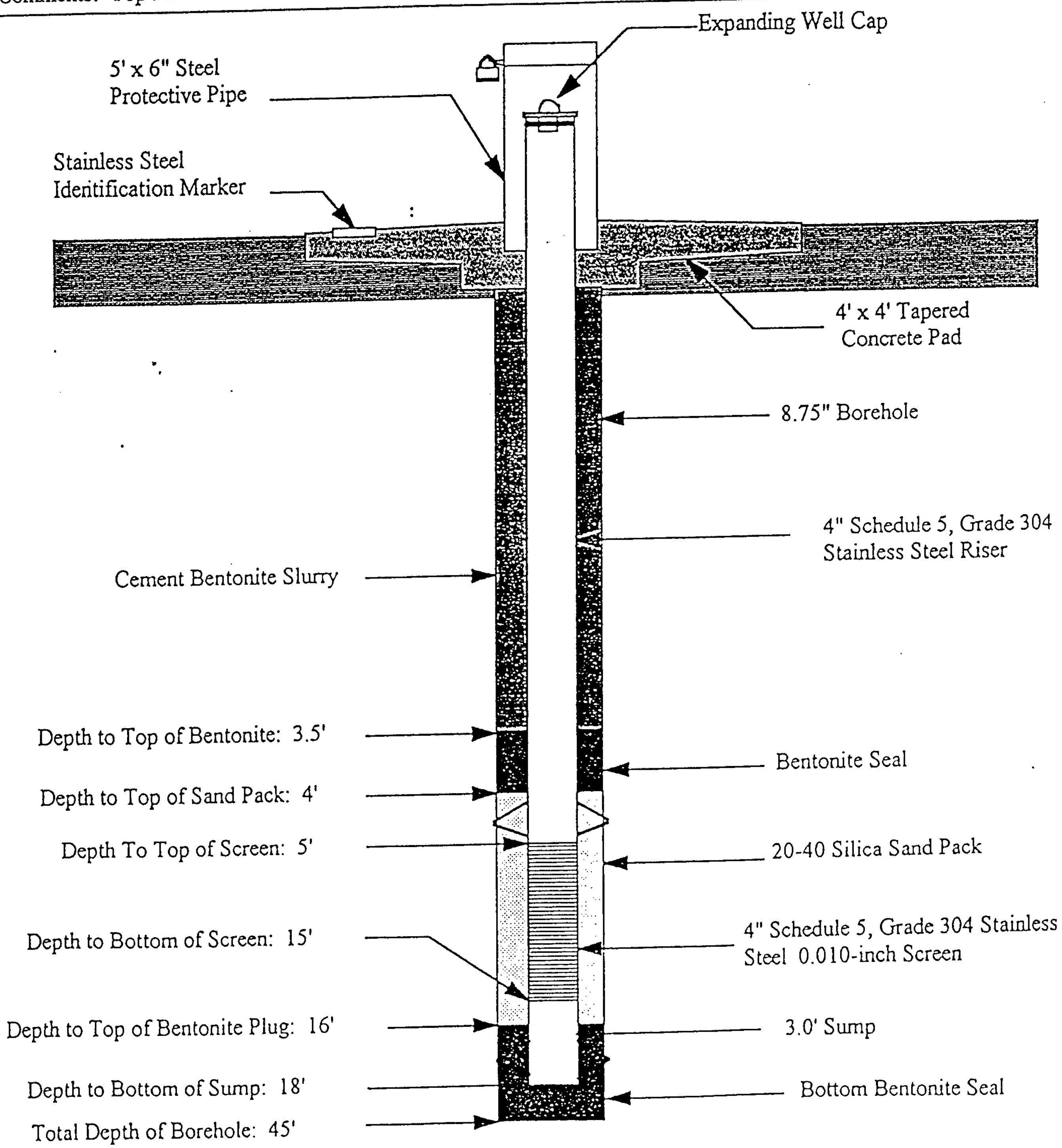
Drawing not to scale

< > Centralizers

WELL CONSTRUCTION SCHEMATIC

Client: Tinker Air Force Base	Well ID: **2-160B**
Location: TAFB, Oklahoma	Site: ST07
Contract No: F34650-94-D-0082/5004 (P & A 3)	Date 4-Inch Riser Set: 06/05/95
Contractor: Brown & Root Environmental	Drilling Method: Auger
Project Manager: David Parker	Ground Level Elev. (AMSL): 1250.99'
Project Geologist: James W. Roberts	Top of Csg. Elev. (AMSL): 1253.56'
Drlg Contractor: Associated Environmental, Inc.	Dedicated Pump: 2-inch Grundfos

Comments: Top Riser: 4" Schedule 40 PVC Casing. 6" thick top bentonite seal set. Sand set 1' above screen.



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Client: TINKER AFB	Project Location: TINKER AFB, OKLAHOMA
Project Name: TINKER 5001	Project Number: 409832

MONITORING WELL 2-62A

DRILLING AND SAMPLING INFORMATION

Boring Location: EAST SIDE OF FIRE TRAINING AREA 2
SURFACE ELEV.(FT): 1246.213
TOTAL DEPTH(FT.): 70
Logged By: M. WILSON
Date Started: 11/22/93
Drilled By: D. MEYER GEOTECHNOLOGY, INC.
Date Completed: 11/29/93
Drill Rig Type: CME-75
Drilling Method: 8" AND 12" HOLLOW STEM AUGERS AND MUD ROTORY WITH 5-5/8" TRICONE ROCK BIT
Sampling Method: 3"x5' CONTINUOUS SAMPLER

Notes: N 150447.890, E 2182152.166

WELL COMPLETION DATA

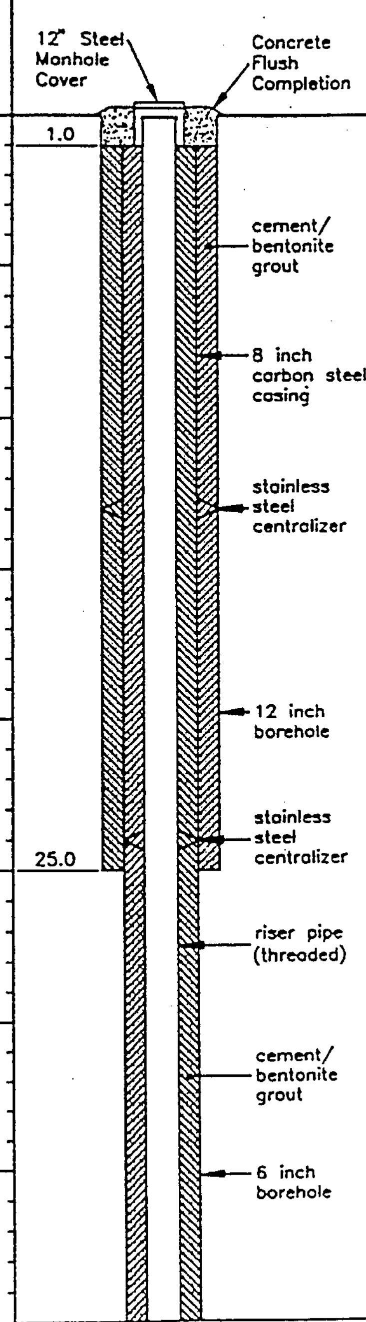
Elev-Top of Casing(ft.):
Ref. Datum: MSL

1. Surf Casing-I.D.(in.): 8 — Depth(ft.): 25 — Type: Carbon Steel
   Centralizers-Type: S.Steel — Depths(ft.): 13
2. Riser Pipe-I.D.(in.): 2 — Depth(ft.): 53.8 — Type: S.Steel
   Centralizers-Type: S.Steel — Depths(ft.): 24, 53
3. Screen Dia.(in.): 2 — Type: S.Steel Wire Wound
   Depth Interval(ft.): 53.8-63.7 — Slot Size(in.): .010
   Centralizers-Type: — Depths(ft.):
4. Filter Pack Type: Silica Sand — Depth Interval(ft.): 52.0-65.0
   Conc. Pad Size: 4'x4'x6"

DESCRIPTION	SAMPLE TYPE / SAMPLE NO.	IN. DRIVEN / IN. RECOVERED	FID, PPM	USCS
CLAYEY SILT - slightly plastic; stiff; moist; red (2.5YR-4/8); roots and gravel at surface; trace caliche nodules; many black carbon imprint stains - hard at 1'	A 1561	36 / 36	0.0	ml
- many caliche nodules - very hard; dry	A 1562	60 / 60	0.0	
	J 5428	24 / 18		
- 2 inch layer of anhydrite/gypsum; light gray (5YR-7/1)	A 1563	36 / 36		
SANDY SILT - 30% very fine grained sand, 70% silt; stiff; compact; becomimg more sandy		60		ml
SILTY SAND - 30% silt, 70% very fine grained sand; compact; moist; red (2.5YR-4/8); few layers (.5 inch) of moderately well cemented sand with trace of light gray laminations	A 1564	/ 60	2.5 2.5	sm
SAND - very fine to fine grained; poorly graded; compact; moist; red (2.5YR-4/8); gradational contact; sand forms thin layers - saturated	A 1565	60 / 60	40 160	sp
SANDY SILT - 20% very fine grained sand, 80% silt; hard; dry; red (2.5YR-4/8); sharp contact; many thin layers of light gray clay		60 / 60	7	ml
SILTY SAND - 40% silt, 60% very fine grained sand; hard; compact; wet; red (2.5YR-4/8); sharp contact; thin layers of light gray clay - small patches of black stains		24 / 24	6	sm
SAND - poorly graded; <5% fines				sp

GEOPHYSICAL LOG (GAMMA): 10 20 30 40

DEPTH IN FEET: 5, 10, 15, 20, 25, 30, 35, 40



DRAFT BY	RPS 1/12/94	DRAFT CHK		PROJ. CHK		APPRV. BY		DWG. NO.	409832-A57 Sheet 1 of 2

Client: TINKER AFB
Project Name: TINKER 5001
Project Location: TINKER AFB, OKLAHOMA
Project Number: 409832

MONITORING WELL 2-62A

DRILLING AND SAMPLING INFORMATION

Boring Location: EAST SIDE OF FIRE TRAINING AREA 2
SURFACE ELEV.(FT): 1246.213
TOTAL DEPTH(FT.): 70
Logged By: M. WILSON
Date Started: 11/22/93
Drilled By: D. MEYER GEOTECHNOLOGY, INC.
Date Completed: 11/29/93
Drill Rig Type: CME-75
Drilling Method: 8" AND 12" HOLLOW STEM AUGERS AND MUD ROTORY WITH 5-5/8" TRICONE ROCK BIT
Sampling Method: 3"x5' CONTINUOUS SAMPLER

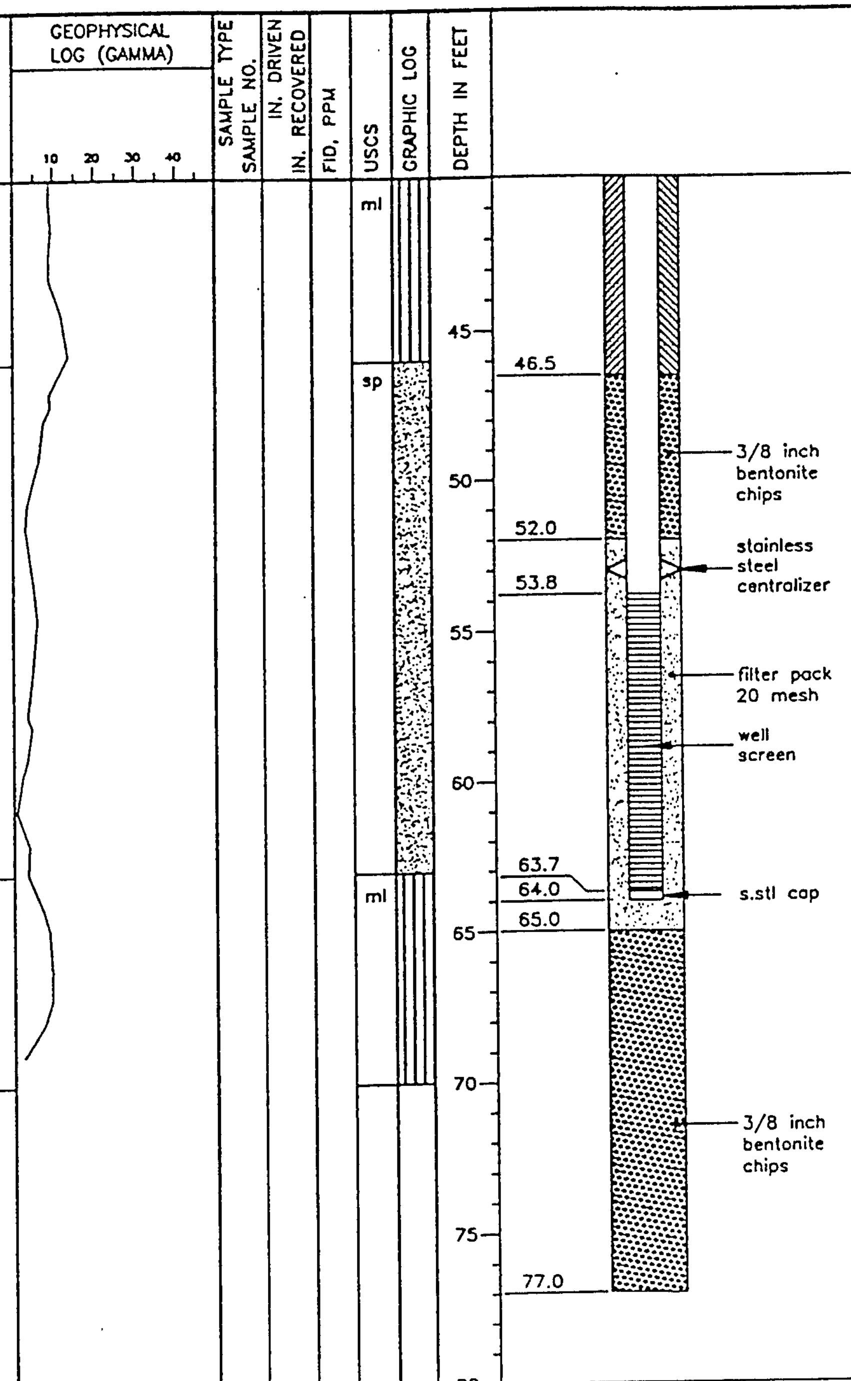
Notes: N 150447.890, E 2182152.166

WELL COMPLETION DATA

Elev-Top of Casing(ft.):
Ref. Datum: MSL

1. Surf Casing-I.D.(in.): 8 — Depth(ft.): 25 — Type: Carbon Steel
   Centralizers-Type: S.Steel — Depths(ft.): 13
2. Riser Pipe-I.D.(in.): 2 — Depth(ft.): 53.8 — Type: S.Steel
   Centralizers-Type: S.Steel — Depths(ft.): 24, 53
3. Screen Dia.(in.): 2 — Type: S.Steel Wire Wound
   Depth Interval(ft.): 53.8-63.7 — Slot Size(in.): .010
   Centralizers-Type: — Depths(ft.):
4. Filter Pack Type: Silica Sand — Depth Interval(ft.): 52.0-65.0
   Conc. Pad Size: 4'x4'x6"

DESCRIPTION	USCS
SILT - hard; dense	ml
SAND - thin layers of silt (46'-54'); clean sand (54'-63')	sp
SILT - hard; dense	ml
TOTAL DEPTH = 70.0 FEET	



DRAFT BY	RPS 1/12/94	DRAFT CHK		PROJ. CHK		APPRV. BY		DWG. NO.	409832-A57 Sheet 2 of 2

Client: TINKER AFB
Project Name: TINKER 5001
Project Location: TINKER AFB, OKLAHOMA
Project Number: 409832

MONITORING WELL 2-63A

DRILLING AND SAMPLING INFORMATION

Boring Location: EAST SIDE OF FIRE TRAINING AREA 2
SURFACE ELEV.(FT): 1243.387
TOTAL DEPTH(FT.): 67
Logged By: M. WILSON
Date Started: 11/19/93
Drilled By: D. MEYER GEOTECHNOLOGY, INC.
Date Completed: 11/23/93
Drill Rig Type: CME-75
Drilling Method: 8" AND 12" HOLLOW STEM AUGERS AND MUD ROTORY WITH 5-5/8" TRICONE ROCK BIT
Sampling Method: 3"x5' CONTINUOUS SAMPLER AND 1-1/2"x2' SPLIT SPOON
Notes: N 150389.964, E 2182043.019

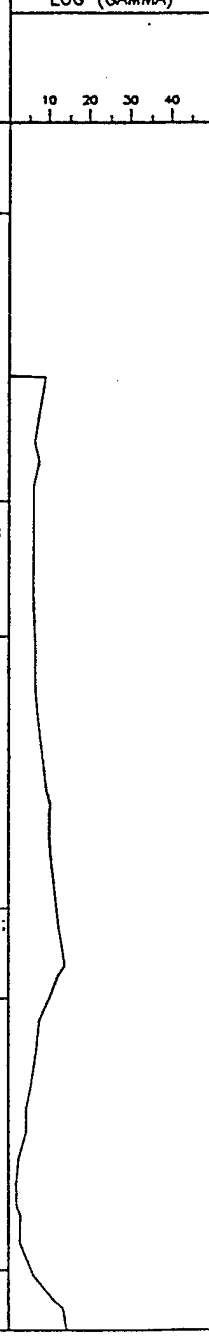
WELL COMPLETION DATA

Elev-Top of Casing(ft.):   Ref. Datum: MSL

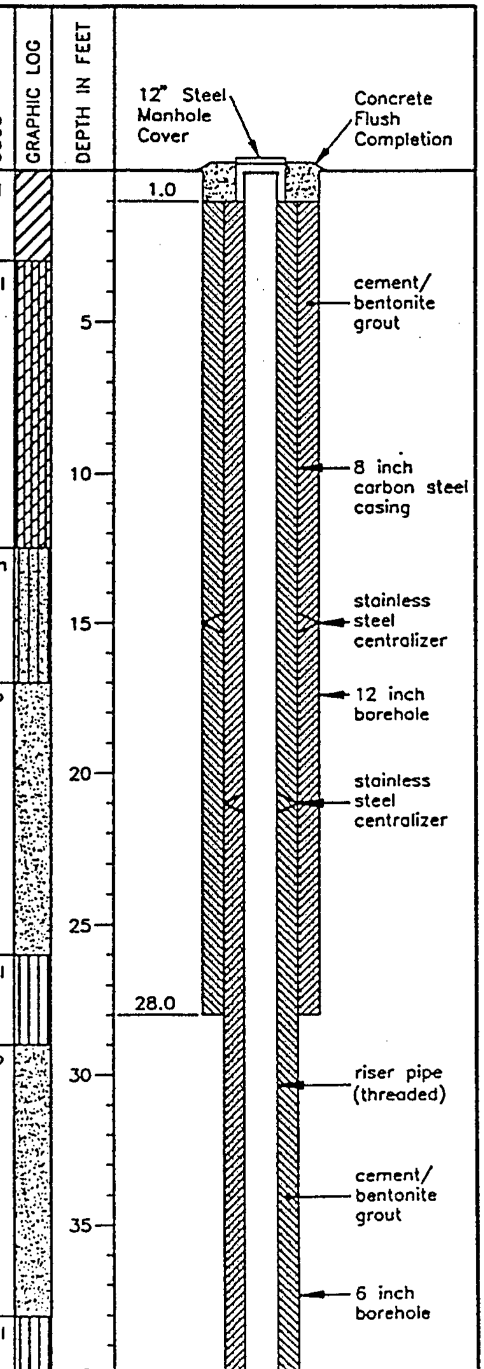
1. Surf Casing-I.D.(in.): 8   Depth(ft.): 28   Type: Carbon Steel
   Centralizers-Type: S.Steel   Depths(ft.): 15
2. Riser Pipe-I.D.(in.): 2   Depth(ft.): 53   Type: S.Steel
   Centralizers-Type: S.Steel   Depths(ft.): 21, 51
3. Screen Dia.(in.): 2   Type: S.Steel Wire Wound
   Depth Interval(ft.): 53.0-63.0   Slot Size(in.): .010
   Centralizers-Type: Depths(ft.):
4. Filter Pack Type: Silica Sand   Depth Interval(ft.): 51-64
   Conc. Pad Size: 4'x4'x6"

DESCRIPTION	SAMPLE TYPE / SAMPLE NO.	IN. DRIVEN / IN. RECOVERED	FID, PPM	USCS
CLAY - slightly plastic; firm; moist; dark grayish brown (10YR-3/2); black carbon imprints; small rootlets; small caliche nodules; gravel fill (0.0'-0.5') - gradational contact	A 1555	36 / 36	0.0	cl
CLAYEY SILT - moderately plastic; firm; moist; red (2.5YR-4/8); black carbon imprint stains - hard; dry; brittle - very hard - 6" anhydrite/gypsum layer; light gray (5YR-7/1)	A 1556; 2-63A; A 1557	60 / 60; 24 / 24; 36 / 36	0.0; 0.0	ml
SILTY SAND - 20% silt, 80% very fine to fine grained sand; hard; compact; moist; sand forms thin (1-2mm) layers - trace of thin laminations of anhydrite/gypsum; light gray (5YR-7/1)	A 1558	60 / 60	0.0	sm
SAND - very fine to fine grained; <10% silt; mostly clean; poorly graded - saturated - some thin layers of sand; lighter red (2.5YR-5/6); poorly cemented	A 1559	60 / 60; 36 / 36	0.0	sp
SILT - slightly plastic; hard; dry; red (2.5YR-4/8); sharp contact		36 / 36		ml
SAND - poorly graded; saturated - silt layer				sp
SILT - hard; dense; several thin layers of sandy silt				ml

GEOPHYSICAL LOG (GAMMA)



GRAPHIC LOG / DEPTH IN FEET



DRAFT BY	RPS 1/13/94	DRAFT CHK		PROJ. CHK		APPRV. BY		DWG. NO.	409832-A58 Sheet 1 of 2

Client: TINKER AFB
Project Name: TINKER 5001

Project Location: TINKER AFB, OKLAHOMA
Project Number: 409832

MONITORING WELL 2-63A

DRILLING AND SAMPLING INFORMATION

Boring Location: EAST SIDE OF FIRE TRAINING AREA 2
Logged By: M. WILSON
Drilled By: D. MEYER GEOTECHNOLOGY, INC.
Drill Rig Type: CME-75
Drilling Method: 8" AND 12" HOLLOW STEM AUGERS AND MUD ROTORY WITH 5-5/8" TRICONE ROCK BIT
Sampling Method: 3"x5' CONTINUOUS SAMPLER AND 1-1/2"x2' SPLIT SPOON
Notes: N 150389.964, E 2182043.019

SURFACE ELEV.(FT): 1243.387
TOTAL DEPTH(FT.): 67
Date Started: 11/19/93
Date Completed: 11/23/93

WELL COMPLETION DATA

Elev-Top of Casing(ft.):
Ref. Datum: MSL

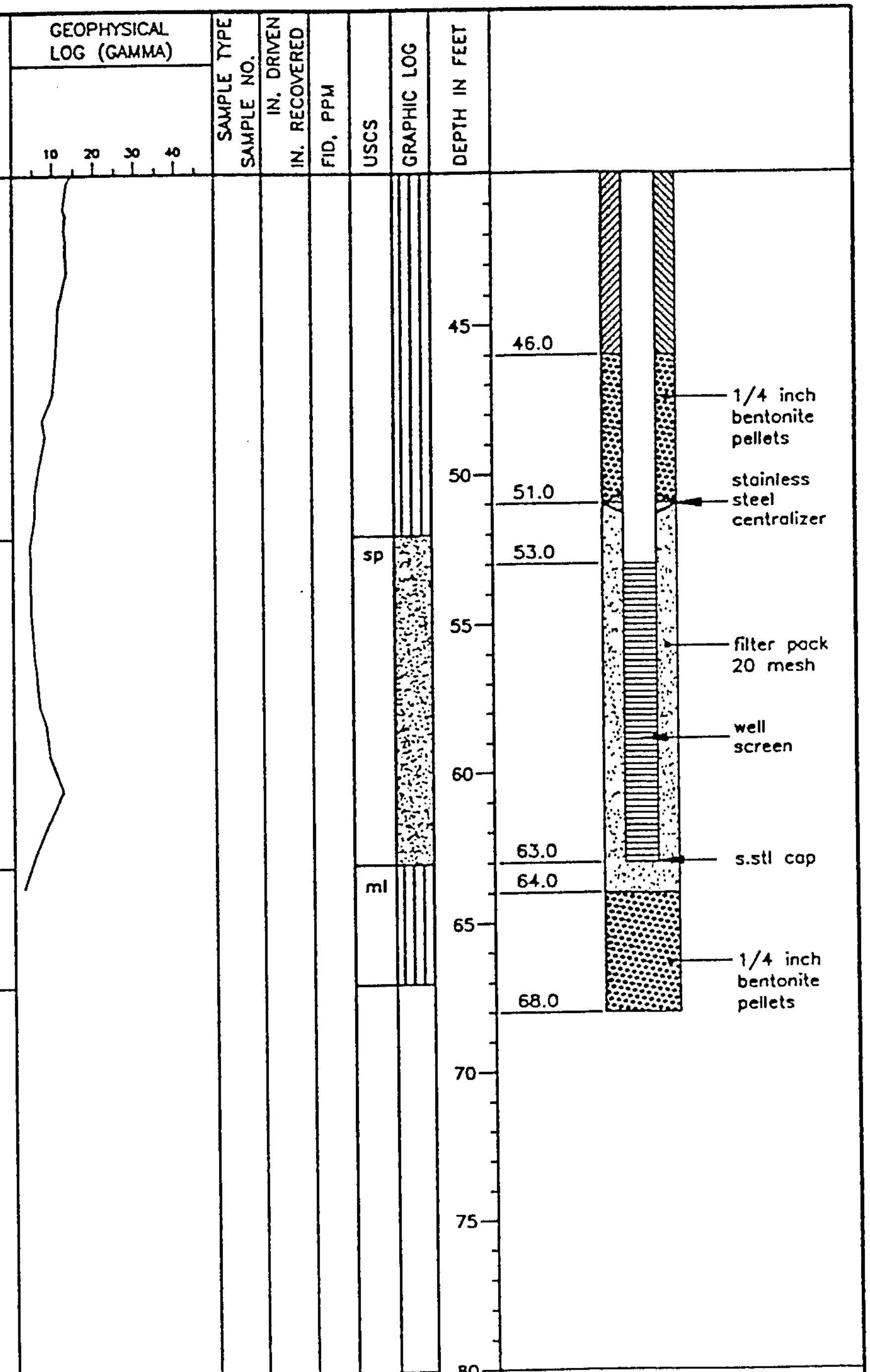
1. Surf Casing-I.D.(in.): 8 Depth(ft.): 28 Type: Carbon Steel
   Centralizers-Type: S.Steel Depths(ft.): 15
2. Riser Pipe-I.D.(in.): 2 Depth(ft.): 53 Type: S.Steel
   Centralizers-Type: S.Steel Depths(ft.): 21, 51
3. Screen Dia.(in.): 2 Type: S.Steel Wire Wound
   Depth Interval(ft.): 53.0-63.0 Slot Size(in.): .010
   Centralizers-Type: Depths(ft.):
4. Filter Pack Type: Silica Sand Depth Interval(ft.): 51-64
   Conc. Pad Size: 4'x4'x6"

DESCRIPTION

SAND - poorly graded; saturated

SILT - hard; dense

TOTAL DEPTH = 67.0 FEET



DRAFT BY	RPS 1/13/94	DRAFT CHK		PROJ. CHK		APPRV. BY		DWG. NO.	409832-A58 Sheet 2 of 2

Client: TINKER AFB
Project Name: TINKER 5001

Project Location: TINKER AFB, OKLAHOMA
Project Number: 409832

MONITORING WELL 2-64A

DRILLING AND SAMPLING INFORMATION

Boring Location: NORTH SIDE OF FIRE TRAINING AREA 2
Logged By: M. WILSON
Drilled By: D. MEYER GEOTECHNOLOGY, INC.
Drill Rig Type: CME-75
Drilling Method: 8" AND 12" HOLLOW STEM AUGERS AND MUD ROTORY WITH 5-5/8" TRICONE ROCK BIT
Sampling Method: 3"x5' CONTINUOUS SAMPLER

SURFACE ELEV.(FT): 1246.052
TOTAL DEPTH(FT.): 75
Date Started: 11/18/93
Date Completed: 11/22/93

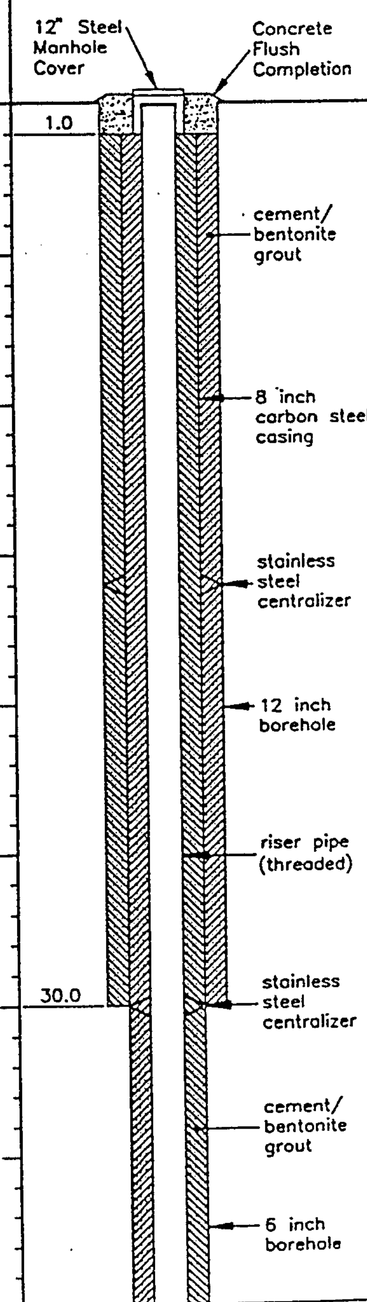
Notes: N 150470.205, E 2181959.365

WELL COMPLETION DATA

Elev-Top of Casing(ft.): Ref. Datum: MSL

1. Surf Casing-I.D.(in.): 8 Depth(ft.): 30 Type: Carbon Steel
   Centralizers-Type: S.Steel Depths(ft.): 16
2. Riser Pipe-I.D.(in.): 2 Depth(ft.): 56 Type: S.Steel
   Centralizers-Type: S.Steel Depths(ft.): 30, 54
3. Screen Dia.(in.): 2 Type: S.Steel Wire Wound
   Depth Interval(ft.): 56-66 Slot Size(in.): .010
   Centralizers-Type: Depths(ft.):
4. Filter Pack Type: Silica Sand Depth Interval(ft.): 54.5-67.0
   Conc. Pad Size: 4'x4'x6"

DESCRIPTION	GEOPHYSICAL LOG (GAMMA) 10 20 30 40	SAMPLE TYPE / SAMPLE NO.	IN. DRIVEN / IN. RECOVERED	PID, PPM	USCS	GRAPHIC LOG	DEPTH IN FEET
CLAY AND GRAVEL – fill; dark grayish brown (10YR-3/2); grass and roots			30				
CLAYEY SILT – slightly plastic; stiff; moist; red (2.5YR-4/8); gravel size caliche nodules; black carbon imprints		A 1548	30 / 60	0.0	ml		5
SILT – hard; dry; red (2.5YR-4/8); brittle; friable		A 1549	60	0.0	ml		
– very hard; dense		A 1550	60				10
		A 1551	60 / 60				
– 2, 2-inch layers of anhydrite/gypsum; light gray (5YR-7/1)				0.0			15
SAND – very fine to fine grained; <10% silt; poorly grade; compact; moist; red (2.5YR-4/8); thin poorly cemented layers; sharp contact		A 1552	60	0.0	sp		
– saturated			60				20
– 30% silt			60 / 60				25
SILTY SAND – 40% silt, 60% very fine grained sand; hard; compact; moist; red (2.5YR-4/8); gradational contact (24'-27'); thin anhydrite/gypsum layer at 28.5'			60 / 60		sm		
SANDY SILT – 30% very fine grained sand, 70% silt – 2-inch layer of anhydrite/gypsum; light gray (5YR-7/1)					ml		30
SILTY SAND – 40% silt, 60% very fine grained sand; poorly cemented; red (2.5YR-4/8); sand forms thin layers; interspersed laminations of anhydrite/gypsum			60		sm		35
SAND – poorly graded; clean					sp		40



DRAFT BY	RPS 1/15/94	DRAFT CHK		PROJ. CHK		APPRV. BY		DWG. NO.	409832-A59 Sheet 1 of 2

Client: TINKER AFB
Project Name: TINKER 5001

Project Location: TINKER AFB, OKLAHOMA
Project Number: 409832

MONITORING WELL 2-64A

DRILLING AND SAMPLING INFORMATION

Boring Location: NORTH SIDE OF FIRE TRAINING AREA 2
Logged By: M. WILSON
Drilled By: D. MEYER
GEOTECHNOLOGY, INC.
Drill Rig Type: CME-75
Drilling Method: 8" AND 12" HOLLOW STEM AUGERS AND MUD ROTORY WITH 5-5/8" TRICONE ROCK BIT
Sampling Method: 3"x5' CONTINUOUS SAMPLER

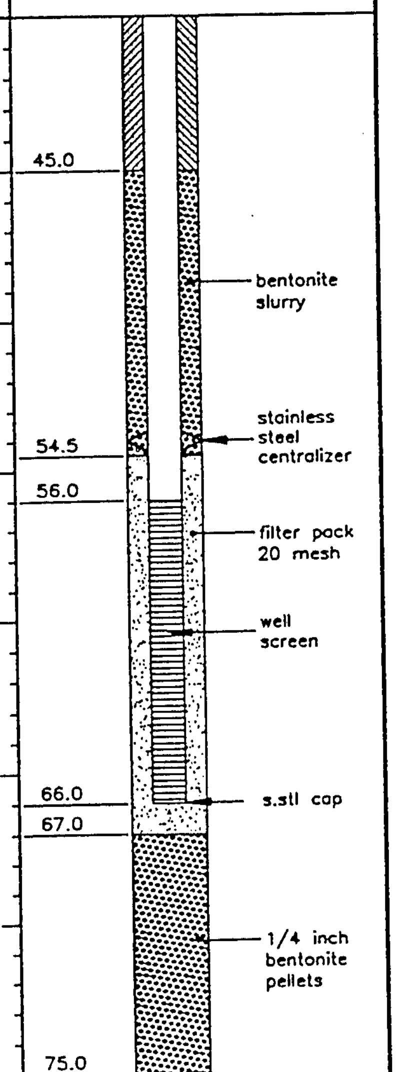
SURFACE ELEV.(FT): 1246.052
TOTAL DEPTH(FT.): 75
Date Started: 11/18/93
Date Completed: 11/22/93

Notes: N 150470.205, E 2181959.365

WELL COMPLETION DATA

Elev-Top of Casing(ft.): Ref. Datum: MSL
1. Surf Casing-I.D.(in.): 8 Depth(ft.): 30 Type: Carbon Steel
   Centralizers-Type: S.Steel Depths(ft.): 16
2. Riser Pipe-I.D.(in.): 2 Depth(ft.): 56 Type: S.Steel
   Centralizers-Type: S.Steel Depths(ft.): 30, 54
3. Screen Dia.(in.): 2 Type: S.Steel Wire Wound
   Depth Interval(ft.): 56-66 Slot Size(in.): .010
   Centralizers-Type: Depths(ft.):
4. Filter Pack Type: Silica Sand Depth Interval(ft.): 54.5-67.0
   Conc. Pad Size: 4'x4'x6"

DESCRIPTION	GEOPHYSICAL LOG (GAMMA) 10 20 30 40	SAMPLE TYPE	SAMPLE NO.	IN. DRIVEN	IN. RECOVERED	PID, PPM	USCS	GRAPHIC LOG	DEPTH IN FEET
SILT - hard; dense; several thin layers of sand							ml		45
									50
SAND - poorly graded; clean							sp		55
									60
									65
SILT - hard; dense							ml		70
TOTAL DEPTH = 75.0 FEET									75
									80



DRAFT BY	RPS 1/15/94	DRAFT CHK		PROJ. CHK		APPRV. BY		DWG. NO.	409832-A59 Sheet 2 of 2

Client: TINKER AFB
Project Name: TINKER 5001

Project Location: TINKER AFB, OKLAHOMA
Project Number: 409832

MONITORING WELL 2-65A

DRILLING AND SAMPLING INFORMATION

Boring Location: NORTHEAST OF FIRE TRAINING AREA 2
SURFACE ELEV.(FT): 1250.976
TOTAL DEPTH(FT.): 79
Logged By: M. WILSON
Date Started: 11/15/93
Drilled By: D. MEYER GEOTECHNOLOGY, INC.
Date Completed: 11/19/93
Drill Rig Type: CME-75
Drilling Method: 8" AND 12" HOLLOW STEM AUGERS

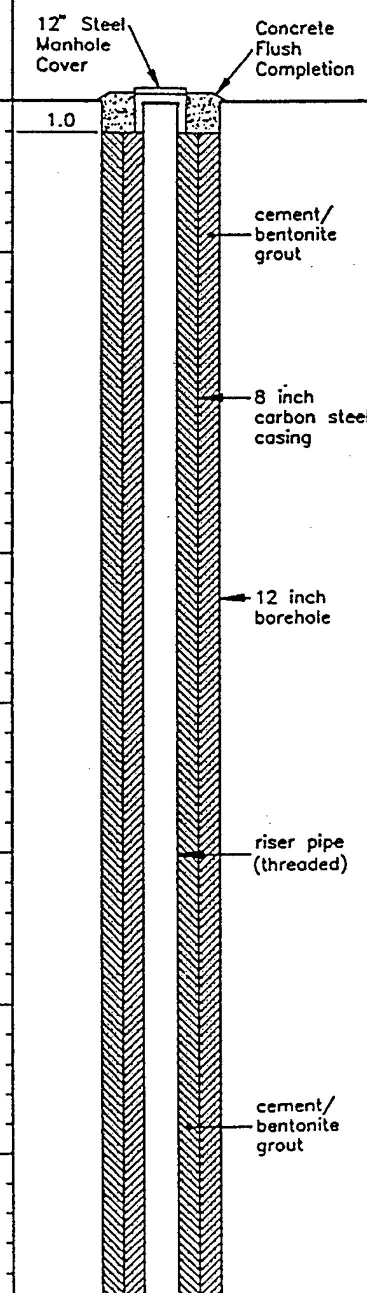
Sampling Method: 3"x5' CONTINUOUS SAMPLER AND 1-1/2"x2' SPLIT SPOON
Notes: N 150698.281, E 2182189.884

WELL COMPLETION DATA

Elev-Top of Casing(ft.):
Ref. Datum: MSL

1. Surf Casing-I.D.(in.): 8 — Depth(ft.): 55 — Type: Carbon Steel
   Centralizers-Type: — Depths(ft.):
2. Riser Pipe-I.D.(in.): 2 — Depth(ft.): 66 — Type: S.Steel
   Centralizers-Type: S.Steel — Depths(ft.): 61
3. Screen Dia.(in.): 2 — Type: S.Steel Wire Wound
   Depth Interval(ft.): 66-76 — Slot Size(in.): .010
   Centralizers-Type: — Depths(ft.):
4. Filter Pack Type: Silica Sand — Depth Interval(ft.): 64-77
   Conc. Pad Size: 4'x4'x6"

DESCRIPTION	GEOPHYSICAL LOG (GAMMA)	SAMPLE TYPE / SAMPLE NO.	IN. DRIVEN / IN. RECOVERED	FID, PPM	USCS	DEPTH IN FEET
CLAY - moderately plastic; stiff; moist; grayish brown (5YR-4/2); grass and roots - gradational contact		A 1540	48 / 48		cl	
GRAVELLY CLAY - slightly plastic; 20% granule size gravel; firm; moist; red (2.5YR-4/8); rootlets; black carbon imprint - hard; dry; brittle - 50% light red caliche - 10% gravel - 30%-40% sand		A 1541	60 / 60	0.0 0.0	cl	5
CLAYEY SILT - nonplastic; very hard; brittle; dry; red (2.5YR-4/8); sharp contact - dense; compact		A 1542	60 / 60	0.0	ml	10
SANDY SILT - 25% very fine grained sand; 75% silt; loose; dry; red (2.5YR-4/8); thin silt layers (0.1-0.5" thick) - few thin seams of very fine grained sand; gray - hard		A 1543 A 1544	60 / 36 30 / 30	0.0	ml	15 20
SILTY SAND - 30% silt, 70% very fine grained sand; compact; stiff; dry; red (2.5YR-4/8); hard to drill - saturated		A 1545 A 1546	9 / 9		sm	25 30
SAND - fine grained; <10% fines; poorly graded; compact; saturated; red (2.5YR-4/8)			24 / 24		sp	
SILTY SAND - 30% silt, 70% very fine grained sand; compact; saturated; red (2.5YR-4/8)			60		sm	35
CLAYEY GRAVELLY SAND - 30% clay, 40% gravel, 30% fine grained sand; loose; saturated; red (2.5YR-4/8)					sc-gc	
SAND - fine grained; poorly graded; compact; saturated; red (2.5YR-4/8)			60		sp	40



	DRAFT BY	RPS 1/15/94	DRAFT CHK		PROJ. CHK		APPRV. BY	DWG. NO.	409832-A60 Sheet 1 of 2

Client: TINKER AFB
Project Name: TINKER 5001

Project Location: TINKER AFB, OKLAHOMA
Project Number: 409832

MONITORING WELL 2-65A

DRILLING AND SAMPLING INFORMATION

Boring Location: NORTHEAST OF FIRE TRAINING AREA 2
SURFACE ELEV.(FT): 1250.976
TOTAL DEPTH(FT.): 79
Logged By: M. WILSON
Date Started: 11/15/93
Drilled By: D. MEYER GEOTECHNOLOGY, INC.
Date Completed: 11/19/93
Drill Rig Type: CME-75
Drilling Method: 8" AND 12" HOLLOW STEM AUGERS

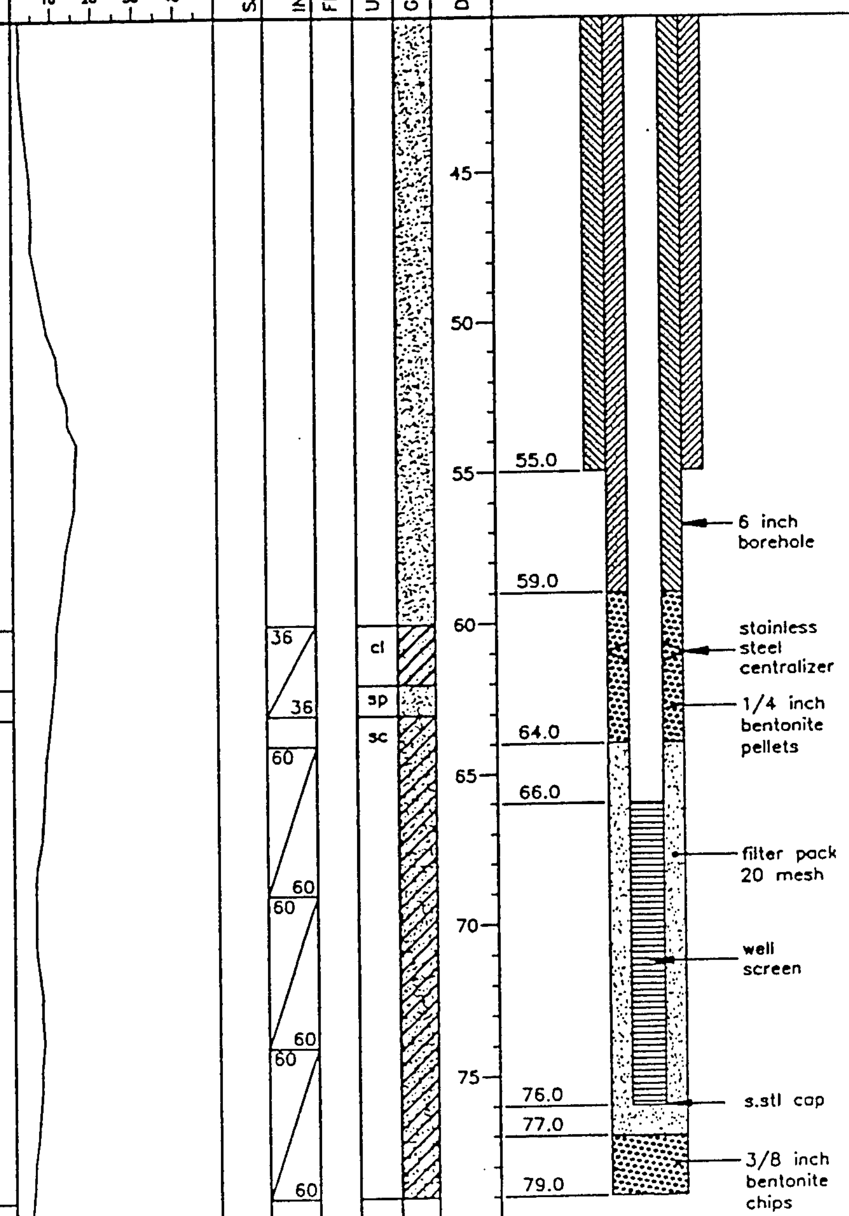
Sampling Method: 3"x5' CONTINUOUS SAMPLER AND 1-1/2"x2' SPLIT SPOON
Notes: N 150698.281, E 2182189.884

WELL COMPLETION DATA

Elev-Top of Casing(ft.): Ref. Datum: MSL

1. Surf Casing-I.D.(in.): 8 Depth(ft.): 55 Type: Carbon Steel
   Centralizers-Type: Depths(ft.):
2. Riser Pipe-I.D.(in.): 2 Depth(ft.): 66 Type: S.Steel
   Centralizers-Type: S.Steel Depths(ft.): 61
3. Screen Dia.(in.): 2 Type: S.Steel Wire Wound
   Depth Interval(ft.): 66-76 Slot Size(in.): .010
   Centralizers-Type: Depths(ft.):
4. Filter Pack Type: Silica Sand Depth Interval(ft.): 64-77
   Conc. Pad Size: 4'x4'x6"

DESCRIPTION	GEOPHYSICAL LOG (GAMMA)	SAMPLE TYPE	SAMPLE NO.	IN. DRIVEN	IN. RECOVERED	FID, PPM	USCS	GRAPHIC LOG	DEPTH IN FEET
- hard									45
- softer									50
- hard									55
SANDY CLAY - 10%-20% fine grained sand; dark red (2.5YR-4/8)				36	36		cl		60
SAND - very fine to fine grained; gray; sharp contact							sp		
CLAYEY SAND - 60%-70% fine grained sand; dark red (2.5YR-4/8); sharp contact				60	60		sc		65
				60	60				70
				60	60				75
TOTAL DEPTH = 79.0 FEET									80

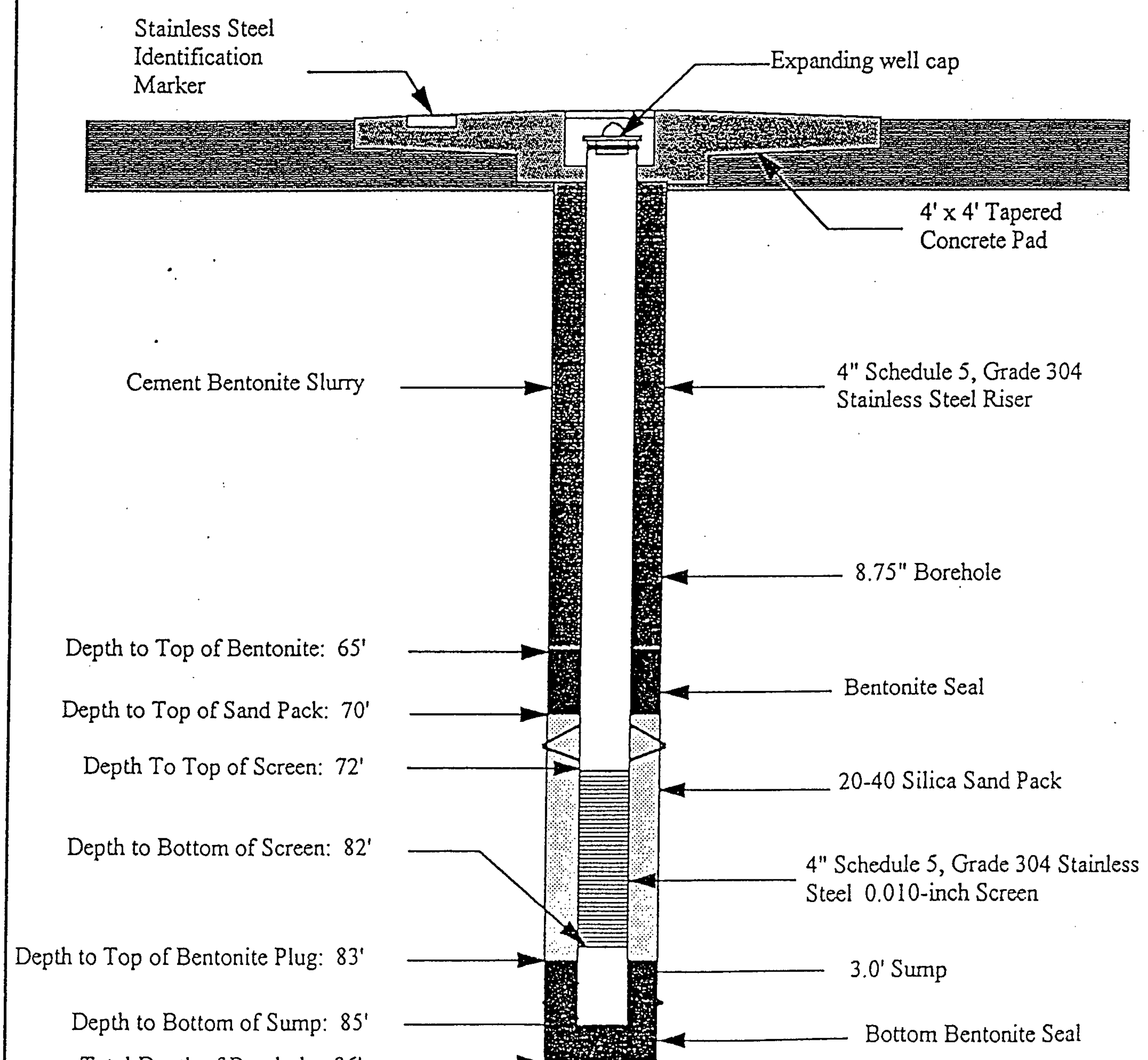


DRAFT BY	RPS 1/15/94	DRAFT CHK		PROJ. CHK		APPRV. BY		DWG. NO.	409832-A60 Sheet 2 of 2

WELL CONSTRUCTION SCHEMATIC

Client: Tinker Air Force Base	Well ID: **2-142A**
Location: TAFB, Oklahoma	Site: BW
Contract No: F34650-94-D-0082/5004 (P & A 3)	Date 4-Inch Riser Set: 05/19/95
Contractor: Brown & Root Environmental	Drilling Method: Mud Rotary
Project Manager: David Parker	Ground Level Elev. (AMSL): 1242.30'
Project Geologist: James W. Roberts	Top of Csg. Elev. (AMSL): 1241.76'
Drlg Contractor: Associated Environmental, Inc.	Dedicated Pump: 2-inch Grundfos

Comments: Top Riser: 4" Schedule 40 PVC Casing.



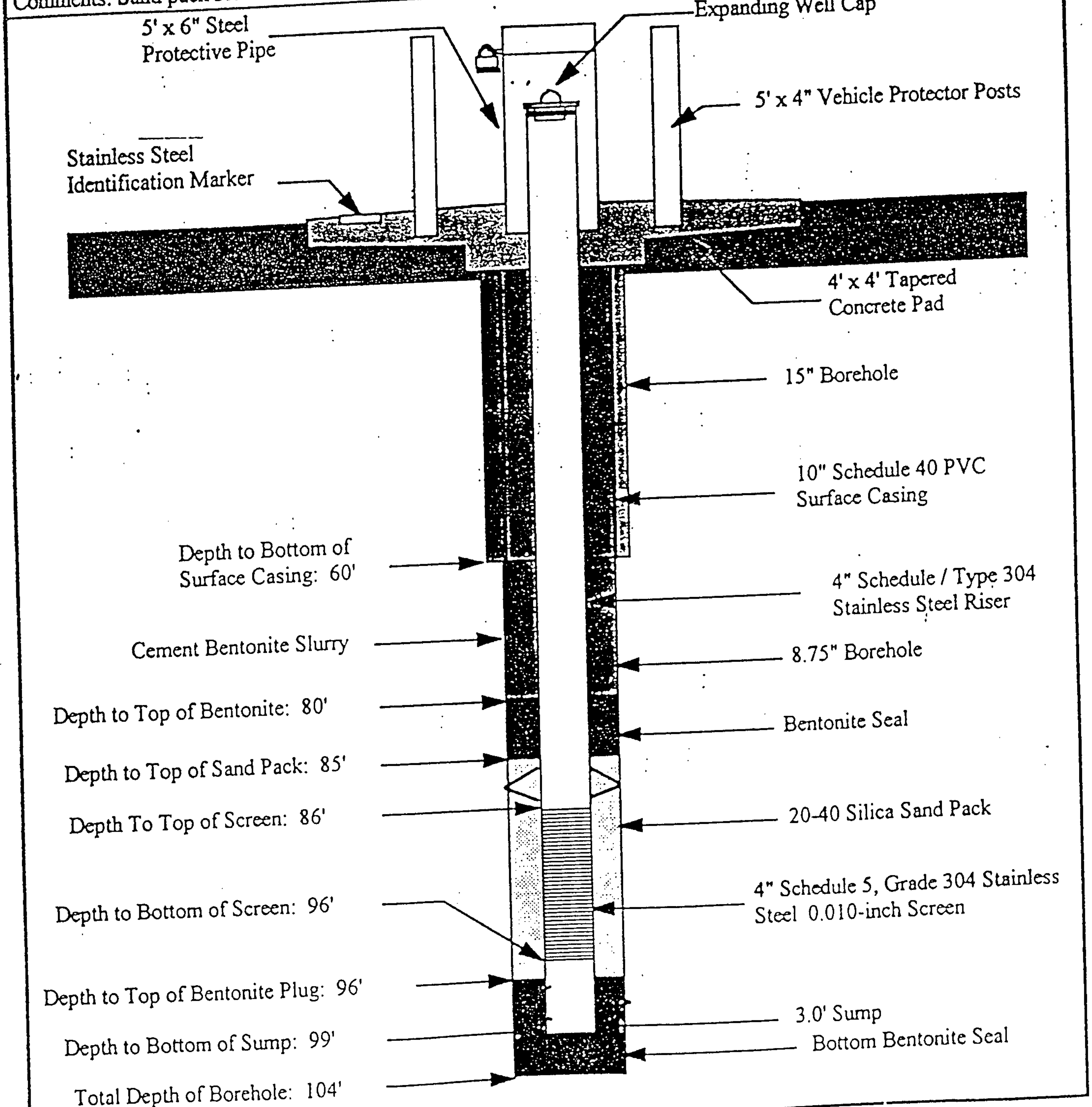
Drawing not to scale

< > Centralizers

WELL CONSTRUCTION SCHEMATIC

Client: Tinker Air Force Base	Well ID: 2-112A
Location: TAFB, Oklahoma	Site: LF15
Contract No: F34650-94-D-0082/5003 (P & A 2)	Date 4-Inch Riser Set: 1/23/95
Contractor: Brown & Root Environmental	Drilling Method: Auger
Project Manager: David Parker	Ground Level Elev. (AMSL): 1248.03'
Project Geologist: James W. Roberts	Top of Csg. Elev. (AMSL): 1251.41'
Drlg Contractor: Associated Environmental Inc.	Dedicated Pump: 2-inch Grundfos

Comments: Sand pack set 1' above screen and even with screen bottom. Top Riser: 4" Schedule 40 PVC Casing.



< > Centralizers

Drawing not to scale

Client: TINKER AFB
Project Name: TINKER 5001

Project Location: TINKER AFB, OKLAHOMA
Project Number: 409832

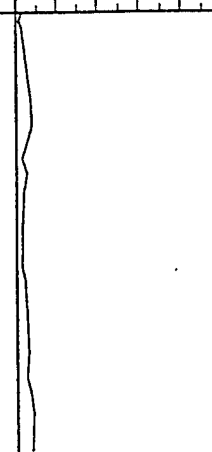
SOIL BORING 2-65P

DRILLING AND SAMPLING INFORMATION

Boring Location: NORTH OF FIRE TRAINING AREA
Logged By: K. KIRSCHENMANN
Drilled By: P. GUERREIN GEOTECHNOLOGY, INC.
Drill Rig Type: CME-75
Drilling Method: 8" HOLLOW STEM AUGER AND MUD ROTARY WITH 3-7/8" BIT
Sampling Method:

SURFACE ELEV.(FT):
TOTAL DEPTH(FT.): 100.0
Date Started: 11/2/93
Date Completed: 11/3/93

Notes: STRATIGRAPHIC TEST USED FOR GEOPHYSICAL LOGGING

DESCRIPTION	GEOPHYSICAL LOG (GAMMA) 10 20 30 40	SAMPLE TYPE	SAMPLE NO.	IN. DRIVEN	IN. RECOVERED	PID, PPM	USCS	GRAPHIC LOG	DEPTH IN FEET
SILTY CLAY							cl		
									85
– very hard						0			90
									95
									100
TOTAL DEPTH = 100.0 FEET									
									105
									110
									115
									120

DRAFT BY	RPS 11/24/93	DRAFT CHK		PROJ. CHK		APPRV. BY		DWG. NO.	409832-A27 Sheet 3 of 3

Analytical Results for Fire Training Area 2
For USZ Groundwater
Tinker Air Force Base, Oklahoma
Table 5-3

Well/Boring:	2-62B 12/10/93		2-62B 12/10/93		2-62B		2-63B 12/10/93		2-64B 12/10/93		2-65B 12/10/93	
Sample ID:	A1601		A1602		A1665		A1600		A1603		A1604	
Depth in Feet:	0 - 0		0 - 0		0 - 0		0 - 0		0 - 0		0 - 0	
Parameters	Result	QFR	Result	QFR	Result	QFR	Result	QFR	Result	QFR	Result	QFR
Metals (mg/L)												
Aluminum	8.2		5.1				5.9		1.4		0.95	
Barium	0.21		0.19				0.35		0.23		0.24	
Calcium	48	N	58	N			61	N	59	N	80	N
Chromium	0.04	N	0.029	N			0.014	N				
Copper	0.043	N	0.049	N								
Iron	11		5.5				13		. 2		1.1	
Lead - Graphite Furnace	0.004		0.0031									
Magnesium	43		52				45		33		52	
Manganese	0.14	N	0.1	N			0.23	N	0.048	N	0.065	N
Potassium											1.7	
Selenium							0.1	N				
Sodium	110		130				59		46		43	
Zinc	0.024	N	0.021	N			0.022	N				
Semivolatile (ug/L)												
1,3-Dichlorobenzene	53		46									
Volatile (ug/L)												
1,1,2-Trichloroethane	9		7.3									
1,1-Dichloroethene	5.7		6									
1,2-Dichlorobenzene	1900	D	1700	D								
1,2-Dichloroethane	500		550		430		1.2	J	2	J		
1,2-Dichloropropane	7		7.3									
1,4-Dichlorobenzene	290	D	250	D								
Benzene	5.4		5.7									
Chlorobenzene	220		240		220				1.2	J		
Trichloroethene	8300	D	8900	D	7900	D	33		96		99	
cis-1,2-Dichloroethene	1600	D	1700	D	1300		45		39		24	
trans-1,2-Dichloroethene	130		140						3.5	J		

Analytical Results for Fire Training Area 2
For USZ Groundwater
Tinker Air Force Base, Oklahoma
Table 5-3

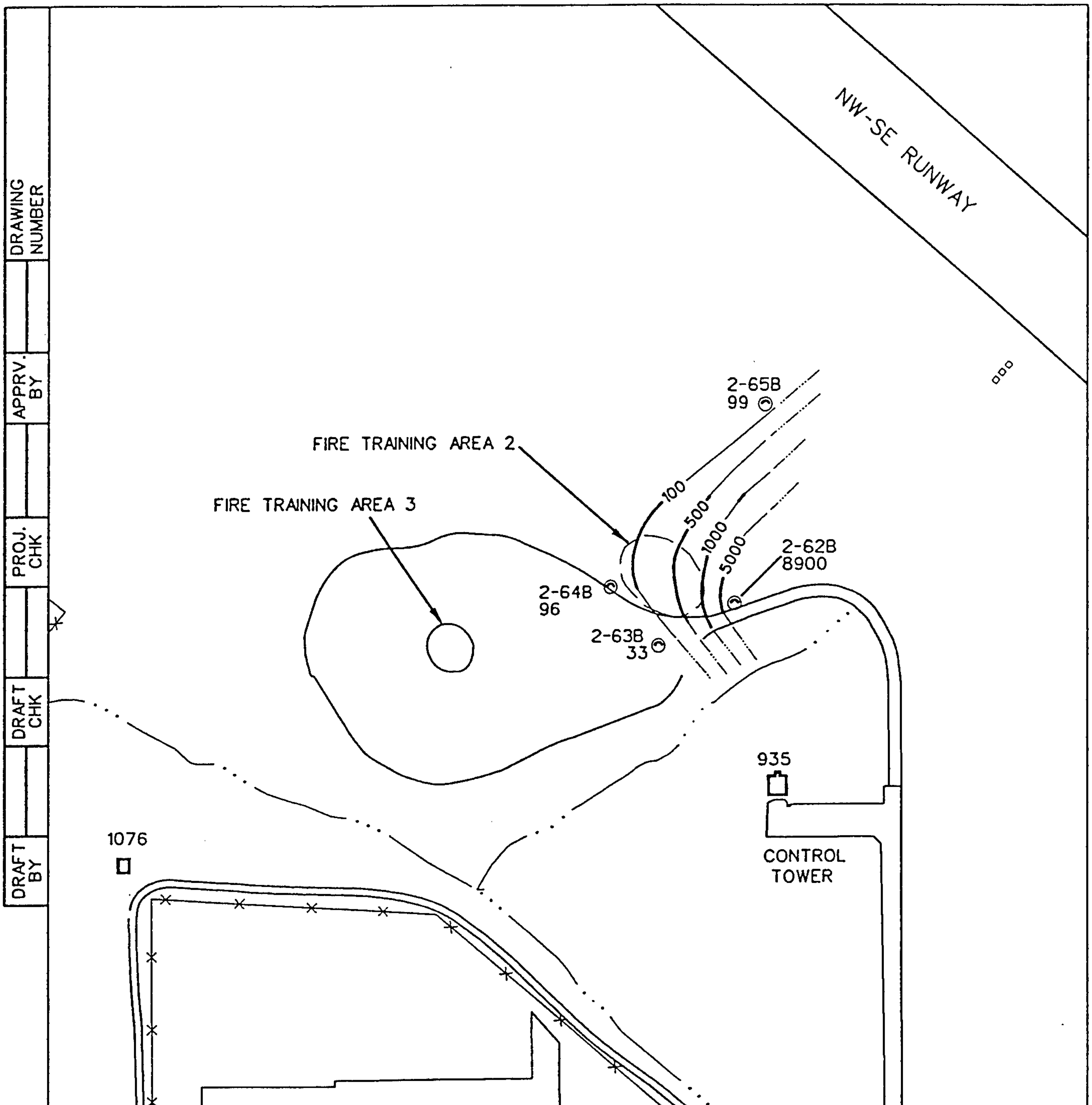
Well/Boring:	2-62B		2-62B		2-62B		2-63B		2-64B		2-65B	
Sample ID:	A1601		A1602		A1665		A1600		A1603		A1604	
Depth in Feet:	0 - 0		0 - 0		0 - 0		0 - 0		0 - 0		0 - 0	
Parameters	Result	QFR	Result	QFR	Result	QFR	Result	QFR	Result	QFR	Result	QFR
Miscellaneous (mg/L)												
Alkalinity, Titrimetric	520		330				470		380		500	
Chemical Oxygen Demand	35											
Chloride by Ion Chrom.	87		89				39		34		57	
Nitrate and Nitrite	2.9		2.7				3.8		3.8		2.6	
Silica	7.3		6.9				8.9		4.3		11	
Sulfate by Ion Chrom.	110		230				36		24		37	
Total Phosphorus	0.15											
Total Dissolved Solids	630		660				510		450		650	
Total Kjeldahl Nitrogen	0.38											
Total Organic Carbon	3		3				2.2		1.2		1.6	
Total Suspended Solids	190		250				750		160		42	

B = Analyte was also found in sample blank
D = Compound identified at a secondary dilution factor.
E = Concentration exceeds instrument calibration range for that specific analysis
J = Concentration is an estimated value
N = Sample is outside of Matrix Spike QC Limit
< = Not detected
QFR = Qualifier
Analytical data has not been validated

Analytical Results for Fire Training Area 2
For LSZ Groundwater
Tinker Air Force Base, Oklahoma
Table 5-4

	12/17/96		12/13		12/13		12/13	
Well/Boring:	2-62A		2-63A		2-64A		2-65A	
Sample ID:	A1648		A1607		A1608		A1609	
Depth in Feet:	0 - 0		0 - 0		0 - 0		0 - 0	
Parameters	Result	QFR	Result	QFR	Result	QFR	Result	QFR
Metals (mg/L)								
Aluminum	1.5		32	N	2.9	N	2.8	N
Arsenic - Graphite Furnace			0.018					
Barium	0.56		3.7		0.56			
Cadmium			0.0066					
Calcium	68		100		61		36	
Chromium	0.021		0.12	N	0.075	N	0.053	N
Copper			0.1					
Iron	1.1		57		4.8		4.3	
Lead - Graphite Furnace			0.025		0.0042			
Magnesium	42		57		35		19	
Manganese	0.016		1.2	N	0.12	N	0.067	N
Nickel			0.079	N	0.067	N		
Potassium			7.3					
Sodium	45		25		23		22	
Zinc			0.1	N	0.021	N	0.028	N
Miscellaneous (mg/L)								
Total Dissolved Solids	450		190		388		258	
Total Kjeldahl Nitrogen							0.26	N
Total Suspended Solids	45		1900		200			
Alkalinity, Titrimetric	390		380		350		190	
Chloride by Ion Chrom.	9.9		17		26		24	
Nitrate and Nitrite	5.3		3.3		1.1		0.78	
Silica	11		8.8		8.6		11	
Sulfate by Ion Chrom.	17		17	N	14	N	24	N
Total Phosphorus			0.19	N			3.9	N

B = Analyte was also found in sample blank
E = Concentration exceeds instrument calibration range for that specific analysis
J = Concentration is an estimated value
N = Sample is outside of Matrix Spike QC Limit
< = Not detected
QFR = Qualifier
Analytical data has not been validated



Map Source: TINKER AFB

LEGEND

2-63B
33 — SHALLOW MONITORING WELL LOCATION, IDENTIFICATION NUMBER, AND TRICHLOROETHENE CONCENTRATION IN $\mu g/L$

FENCE

DRAINAGE

100 — LINE OF EQUAL TRICHLOROETHENE CONCENTRATION IN $\mu g/L$ (DASHED WHERE INFERRED)

N

0 200
FEET

G:\TINKER\40983202.135
Do Not Scale This Drawing

FIGURE 5-5
ISOPLETH MAP OF TRICHLOROETHENE CONCENTRATION OF THE UPPER SATURATED ZONE AT FIRE TRAINING AREA 2

PREPARED FOR

TINKER AFB
OKLAHOMA

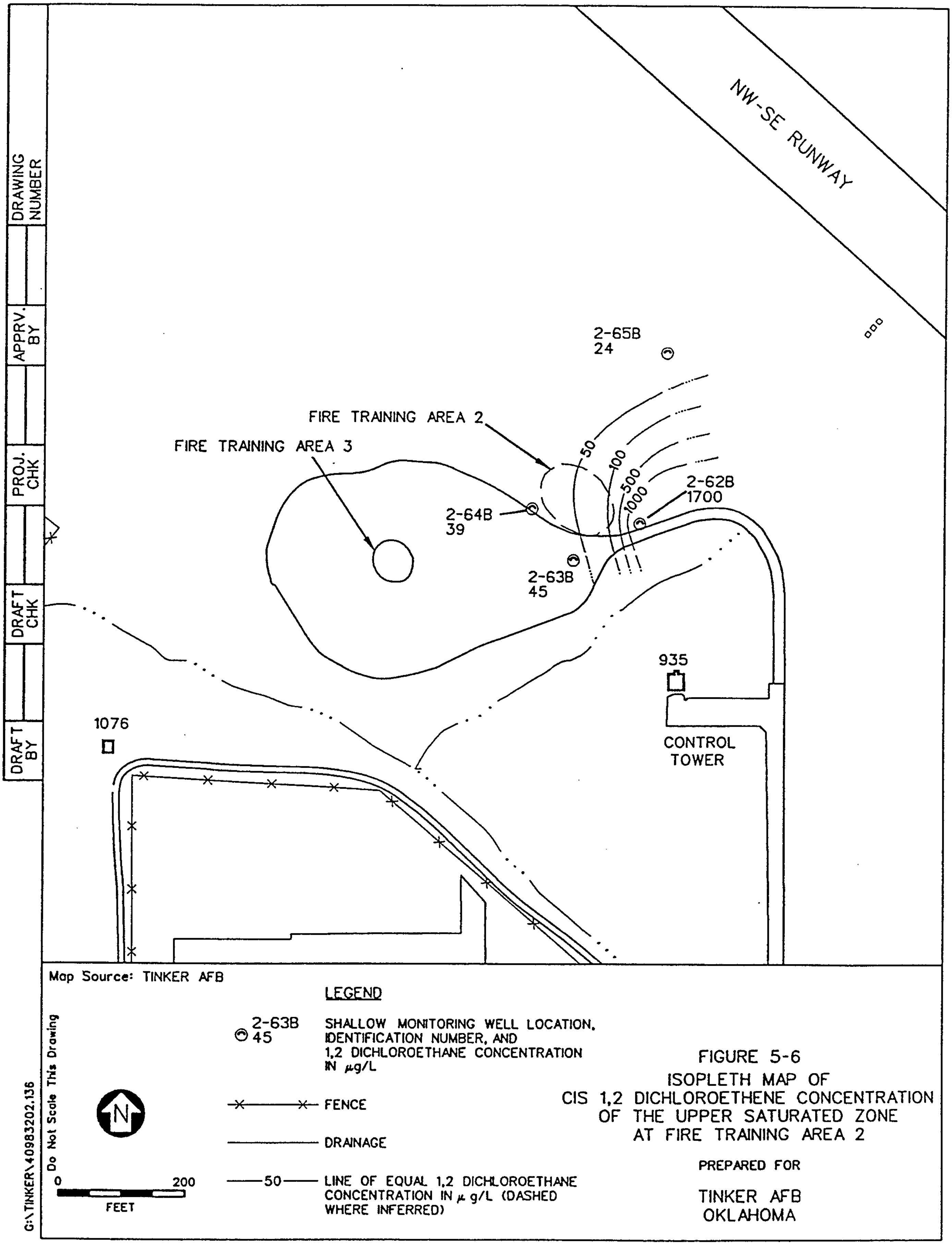


FIGURE 5-6
ISOPLETH MAP OF
CIS 1,2 DICHLOROETHENE CONCENTRATION
OF THE UPPER SATURATED ZONE
AT FIRE TRAINING AREA 2

PREPARED FOR

TINKER AFB
OKLAHOMA

APPENDIX C

ADDITIONAL SITE DATA
AREA A

WATER & SOIL CONSULTANTS, INC.

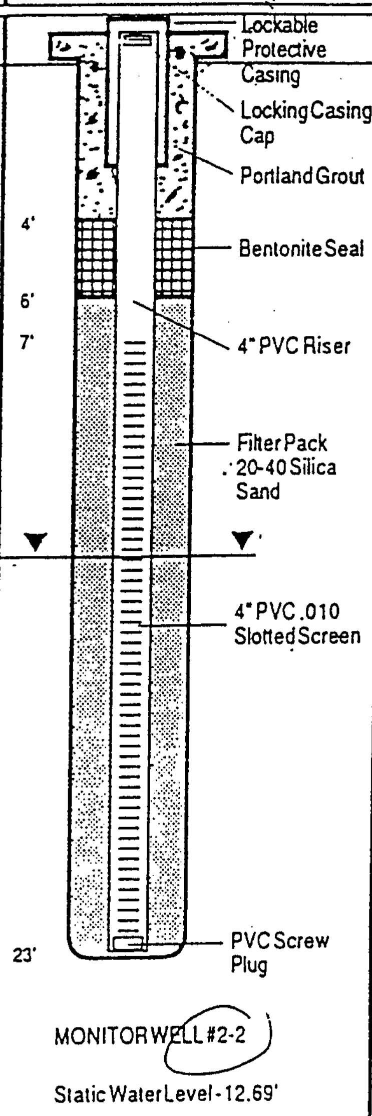
P.O. Box 881 • NORMAN, OKLAHOMA 73070 • (405) 329-2011

CP

BORING LOG

Depth (feet)	Lithology Description	Graphic Log	USCS Class.
0			
.67	Topsoil; clay		
2.3	Fill material; red brown clay		
5.9	Clay; plastic; brown		
10.2	Clay; plastic; brown red		
10.4	Clay; gray		
12	Silt; clayey; soft; red brown		12.69'
17	Silt; some fine sand; clayey; red brown; thinly laminated		
17.5	Siltstone; red brown; thinly laminated		
19	Clay; plastic; firm; red brown		
20	Sandstone; fine-medium grained; red brown; water saturated		
21.5	Siltstone; red brown; thinly laminated		
23	Sand; fine grained; red brown; wet; auger refusal at 23'		
25	T.D. 23'		
30			

Well Construction



Remarks

PID READING	
1.5'	0 ppm
4.1'	0 ppm
6.5'	0 ppm
7.5'	4 ppm
9.2'	512 ppm
10.3'	25 ppm
11'	406 ppm
12'	3 ppm
14'	48 ppm
15'	12 ppm
17'	14 ppm
17.5'	4 ppm
19.5'	5 ppm
21'	0 ppm
21.75'	1 ppm
22.5'	0 ppm

Project Number: 90-164	Client: USAF - POL SITE "A"	Driller: A. W. Pool, Inc.
Boring Number: SB-7	Date Drilled: 20 May 1991	Drill Type: Hollow Stem Auger
Logged By: DLW	Elevation: 1242.34 Feet	

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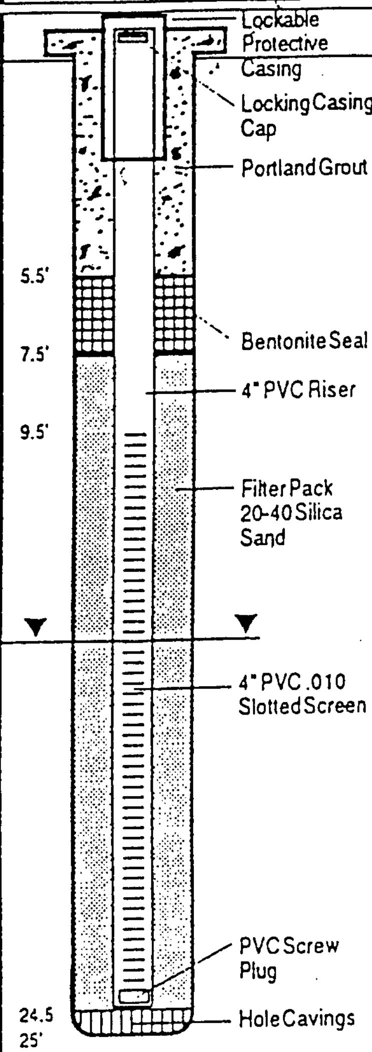
BORING LOG

Depth (feet)	Lithology Description	Graphic Log	USCS Class.
0			
	No samples		
2	Clay; slightly silty; plastic; mottled dark brown to red		
5			
6	Clay; plastic; brown red		
7	Clay; plastic; red; thin bedded and alternating with thin bedded, red brown clayey silt		
10			
12	Silt; very clayey; brown red		
14	Clay; silty; brown red		14.86'
15	Siltstone; gray green		
17	Sand; fine grained; silty; brown red; massive bedded in upper 2', thin bedded below; top water saturation occurs at 19' - 20'		
20			
24	Sand; fine grained; light gray		
25	T.D. 25'		
30			

Well Construction



MONITOR WELL #2-3

Static Water Level - 14.86'

Remarks

PID READING	
3'	0 ppm
6'	0 ppm
7'	582 ppm
8'	315 ppm
9'	11 ppm
10'	9 ppm
13'	577 ppm
14'	157 ppm
15'	15 ppm
16'	452 ppm
17'	217 ppm
18'	17 ppm
20'	5 ppm
23'	16 ppm
25'	0 ppm

Project Number: 90-164	Client: USAF - POL SITE "A"	Driller: A. W. Pool, Inc.
Boring Number: SB-8	Date Drilled: 23 May 1991	Drill Type: Hollow Stem Auger
Logged By: JLT	Elevation: 1242.60 Feet	

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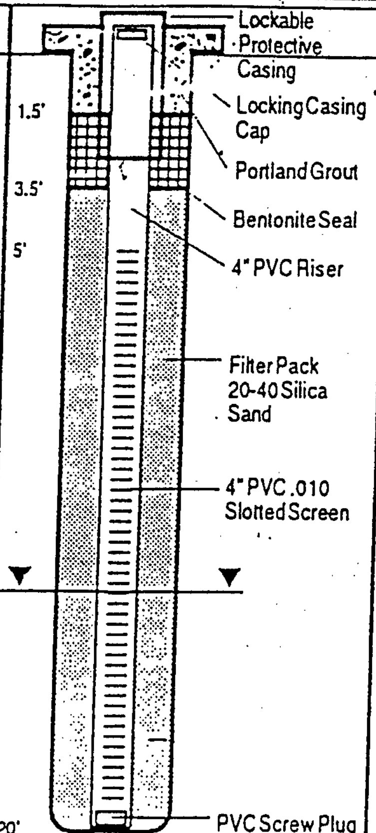
CF

BORING LOG

Depth (feet)	Lithology Description	Graphic Log	USCS Class.	Well Construction	Remarks
0					PID READING
0–2	Fill material				
2	Clay; silty; mottled gray; soft				3' 0 ppm
5					5' 32 ppm
7	Silt; very clayey; red brown; crumbly				7' 4 ppm 8' 3 ppm
9.5 / 10	Silt to fine sand; red brown; loosely to well cemented				10' 362 ppm
12	Silt to fine sand; red brown; alternating thin zones of loosely and well cemented material		13.83'		12' 745 ppm 14' 437 ppm
15	Sandstone; fine grained; red brown; thinly laminated; water saturated at top				15' 563 ppm 15' 566 ppm
16	Auger refusal at 16' - drilled without core barrel to 20'				
20	T.D. 20' *Note: Water level in boring at 14.5' after 20 minutes with thin floating layer of free product.*				
25					
30					



MONITOR WELL #2-4

Top Fuel - 12.67'
Top Water - 17.12'
Effective Static Water Level - 13.83'

Project Number: 90-164	Client: USAF - POL SITE "A"	Driller: A. W. Pool, Inc.
Boring Number: SB-4	Date Drilled: 20 May 1991	Drill Type: Hollow Stem Auger
Logged By: DLW	Elevation: 1243.22 Feet	

2-503

Client: TINKER AFB
Project Name: TINKER 5000
Project Location: TINKER AFB, OKLAHOMA
Project Number: 409802

MONITORING WELL 2-50[

DRILLING AND SAMPLING INFORMATION

Boring Location: EAST OF CIVIL ENGINEERING BLDG
Logged By: V. CRNICH
Drilled By: B. HYBER NESCO
Drill Rig Type: B-61 HD
Drilling Method: 8-1/4" HOLLOW STEM AUGER
Sampling Method: 5'x4" CONTINUOUS SAMPLER AND 2'x2" SPLIT SPOON

PAD ELEV.(FT): 1241.38
TOTAL DEPTH(FT.): 23
Date Started: 10/25/93
Date Completed: 10/26/93

WELL COMPLETION DATA

Elev-Top of Casing(ft.): 2141.30 Ref. Datum: NGVD

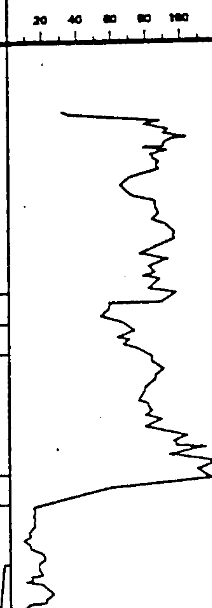
1. Riser Pipe-I.D.(in.): 2 Depth(ft.): 8.0 Type: S.Stee
   Centralizers-Type: S.Steel Depths(ft.): 7.0
2. Screen Dia.(in.): 2 Type: S.Steel Millslotted
   Depth Interval(ft.): 8.0-17.85 Slot Size(in.): .010
   Centralizers-Type: Depths(ft.):
3. Filter Pack Type: Silica Sand Depth Interval(ft.): 5.0-18.0
   Conc. Pad Size: 4'x4'x6"

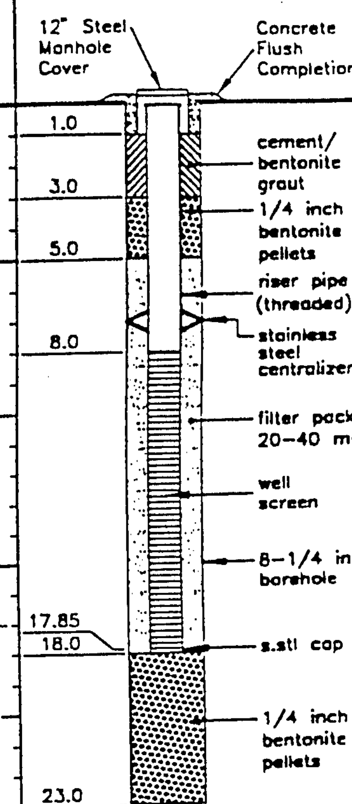
Notes: GEOTECH SAMPLES COLLECTED FROM THE 5-7' AND THE 12-14' INTERVALS;
SPLIT SPOON HAMMERED TO 100 BLOW COUNTS BEFORE PULLING IT OUT OF HOLE
COORDINATES-NAD 27: N158461.793, E 2180201.105

DESCRIPTION	SAMPLE TYPE / SAMPLE NO.	IN. DRIVEN / IN. RECOVERED	PID	USCS	DEPTH IN FEET
CLAY - slightly plastic; firm; dark brown (5YR-3/3); moist - stiff; red (2.5YR-4/6)	A 1341 J 5424	60 / 36 60 / 56	260	cl	0-8
CLAYEY SAND - 60% very fine to fine grained sand; compact; red (2.5YR-4/6); moist; strong hydrocarbon odor	A 1342			sc	
CLAY - nonplastic; hard; small band of whiteish green clay at approx. 10'; red (2.5YR-4/6); dry; strong hydrocarbon odor	A 1343 J 5423	24 / 14 24 / 18		cl	10
SANDY CLAY - nonplastic; stiff; minor bands of whiteish green clay; red (2.5YR-4/6); dry; hydrocarbon odor - hard		12 / 12	158	cl	15
CLAY - nonplastic; hard; slightly sandy; small band of sandy green clay at approx. 15'; red (2.5YR-4/6); dry		24 / 6		sp	
SAND - medium grained; loose; greenish gray (5Y-7/1); wet; hydrocarbon odor; very hard interval (unable to drive split spoon) - driller states hardzone broke at approx. 16.8'		24 / 12	46	sm	
SILTY SAND - 75% fine to medium grained sand; loose; soupy; dark brown (7.5YR-3/3); wet - 100 blow counts		24 / 10		sp	20
SAND - fine grained; loose; slightly silty; reddish brown (2.5YR-4/3); wet; weak hydrocarbon odor		24 / 8			

TOTAL DEPTH = 23.0 FEET

GEOPHYSICAL LOG (GAMMA)





DRAFT BY	RPS 11/17/93	DRAFT CHK		PROJ. CHK		APPRV. BY		DWG. NO.	409802-A23 Sheet 1 of 1

2-513

Client: TINKER AFB
Project Name: TINKER 5000
Project Location: TINKER AFB, OKLAHOMA
Project Number: 409802

MONITORING WELL 2-5

DRILLING AND SAMPLING INFORMATION

Boring Location: SOUTHEAST OF BUILDING 410
PAD ELEV.(FT): 1241.45
TOTAL DEPTH(FT.): 23
Logged By: V. CRNICH
Date Started: 10/21/93
Drilled By: T. PATTERSON NESCO
Date Completed: 10/21/93
Drill Rig Type: SIMCO 2800 HS HT
Drilling Method: 6" HOLLOW STEM AUGER

Sampling Method: 2'x 2" SPLIT SPOON

Notes: CREW USING CRISCO AS LUBRICANT ON SPLIT SPOONS;
HIT WATER AT 16 FEET
COORDINATES-NAD 27: N 158301.112, E 2180427.530

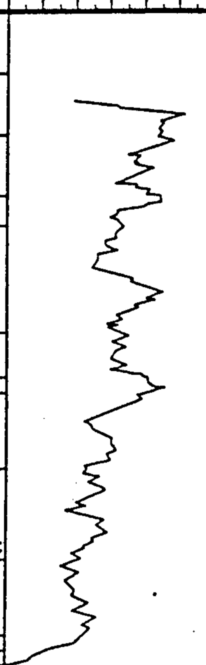
WELL COMPLETION DATA

Elev-Top of Casing(ft.): 1241.29 **Ref. Datum:** NGVD
1. **Riser Pipe-I.D.(in.):** 2 **Depth(ft.):** 8.0 **Type:** S.Steel
   Centralizers-Type: S.Steel **Depths(ft.):** 7.0
2. **Screen Dia.(in.):** 2 **Type:** S.Steel Millslotted
   Depth Interval(ft.): 8.0-17.85 **Slot Size(in.):** .010
   Centralizers-Type: **Depths(ft.):**
3. **Filter Pack Type:** Silica Sand **Depth Interval(ft.):** 5.3-18.0
   Conc. Pad Size: 4'x4'x6"

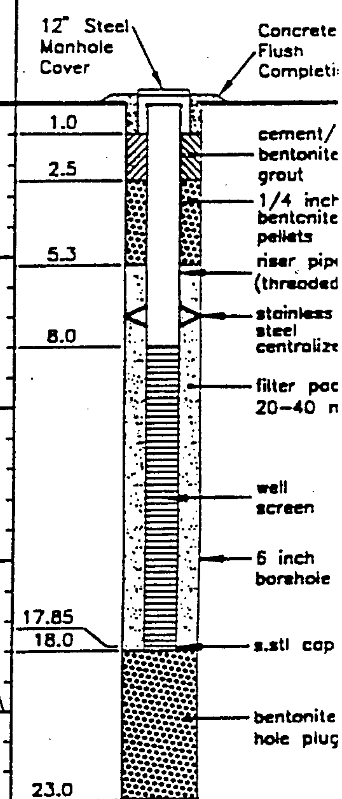
DESCRIPTION	SAMPLE TYPE / SAMPLE NO.	IN. DRIVEN / IN. RECOVERED	PID	USCS
TOPSOIL - grass; poor recovery		24 / 6		
CLAY - slightly plastic; firm; dark reddish gray (10R-4/1); moist; poor recovery		24 / 12		cl
SANDY CLAY - slightly plastic; soft; weak red (10R-4/4); moist; poor recovery		24 / 6		cl
CLAY - slightly plastic; hard; brownish red (10R-3/1); moist	A 1334	12 / 12	3.9	cl
SANDY CLAY - 30% fine grained sand; stiff; brownish red (2.5YR-4/6); moist; weak hydrocarbon odor - stronger hydrocarbon odor at 8' - 30% sand; hydrocarbon odor	A 1335	12 / 12; 24 / 18	31	cl
CLAYEY SAND - 75% fine grained sand; compact; brownish red (2.5YR-4/6); moist; strong hydrocarbon odor	A 1336	24 / 18	493; 57.9	sc; cl; sc
SANDY CLAY - firm; brownish red (2.5YR-4/6); moist; faint hydrocarbon odor		24 / 16; 12 / 12	45; 19	
CLAYEY SAND - 80% fine grained sand; compact; clay seams; red (2.5YR-4/6); moist		12 / 12	0.0	sm
SILTY SAND - 80% very fine to fine grained sand; compact; red (2.5YR-4/6); moist to wet no odor - 25% silt, 75% fine grained sand; loose; wet - moist; weak hydrocarbon odor		24 / 21; 12 / 10		sm
SILTY CLAYEY SAND - 60% very fine to fine grained sand; loose; red (2.5YR-4/6); moist - firm at 18.8' - no recovery at 19' - slightly plastic; 75% fine grained sand; wet		24 / 12		sm
SILTY SAND - 75% fine grained sand; firm; some clay stringers; red (2.5YR-4/6) and pinkish white (7.5YR-7/4); dry		12 / 12		sc
CLAYEY SAND - 55% fine grained sand; firm; red (2.5YR-4/6); moist		12 / 12		sp
SAND - fine grained; loose; slightly silty; red (2.5YR-4/6); moist - coarse to fine grained; loose; wet				sw

TOTAL DEPTH = 23.0 FEET

GEOPHYSICAL LOG (GAMMA)



GRAPHIC LOG — DEPTH IN FEET: 5, 10, 15, 20, 25, 30, 35, 40



DRAFT BY	RPS 11/17/93	DRAFT CHK		PROJ. CHK		APPRV. BY		DWG. NO.	409802-A24 Sheet 1 of 1

2-523

Client: TINKER AFB
Project Name: TINKER 5000
Project Location: TINKER AFB, OKLAHOMA
Project Number: 409802

MONITORING WELL 2-5[illegible]

DRILLING AND SAMPLING INFORMATION

Boring Location: AREA A
PAD ELEV.(FT): 1239.95
TOTAL DEPTH(FT.): 23
Logged By: V. CRNICH
Date Started: 10/22/93
Drilled By: T. PATTERSON NESCO
Date Completed: 10/25/93
Drill Rig Type: SIMCO 2800 HS HT
Drilling Method: 6" HOLLOW STEM AUGER
Sampling Method: 2'x 2" SPLIT SPOON

WELL COMPLETION DATA

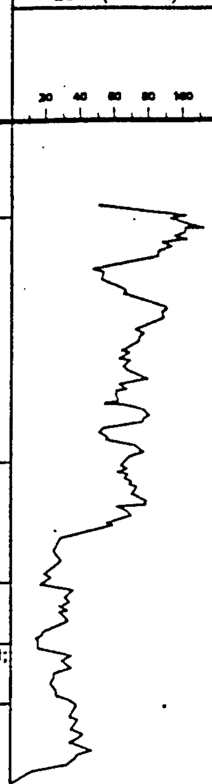
Elev-Top of Casing(ft.): 1241.81 **Ref. Datum:** NGVD
1. **Riser Pipe-I.D.(in.):** 2 **Depth(ft.):** 8.1 **Type:** S.Steel
   - **Centralizers-Type:** S.Steel **Depths(ft.):** 7.0
2. **Screen Dia.(in.):** 2 **Type:** S.Steel Millslotted
   Depth Interval(ft.): 8.1-17.85 **Slot Size(in.):** .010
   Centralizers-Type: **Depths(ft.):**
3. **Filter Pack Type:** Silica Sand **Depth Interval(ft.):** 4.5-18.[illegible]
   Conc. Pad Size: 4'x4'x6"

Notes: CREW USING CRISCO AS LUBRICANT ON SPLIT SPOONS;
GEOTECH SAMPLES COLLECTED FROM THE 5-7' AND THE 13-15' INTERVAL
COORDINATES-NAD 27: N 158292.472, E 2180247.692

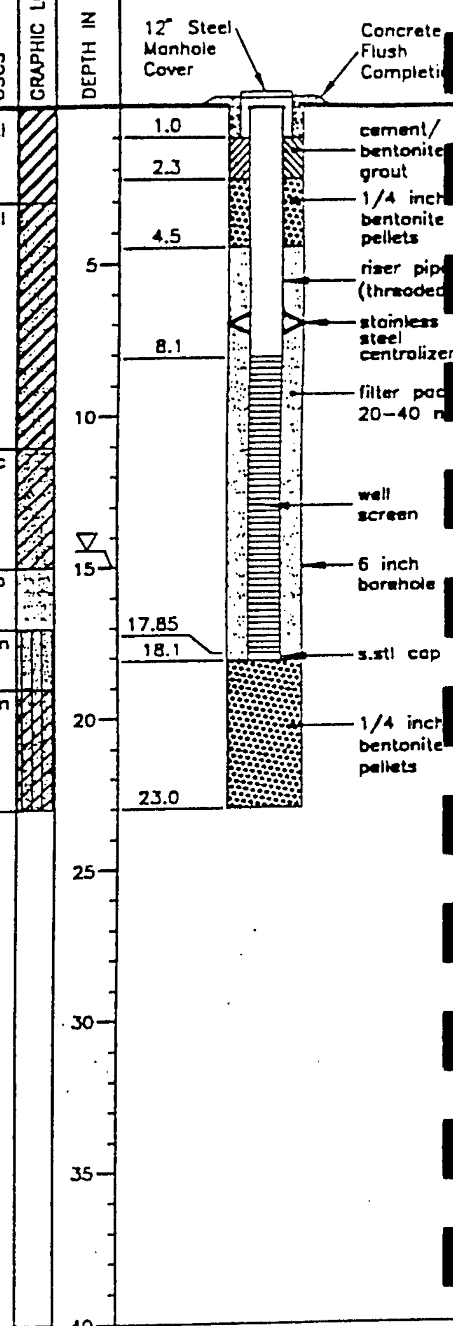
DESCRIPTION	SAMPLE TYPE / SAMPLE NO.	IN. DRIVEN / IN. RECOVERED	PID	USCS
CLAY - nonplastic; firm; topsoil; minor chunks of gravel; dark reddish brown (5YR-3/3); moist - no recovery		24 / 12 12 / 0		cl
SANDY CLAY - nonplastic; hard; slightly sandy; dark brown (10YR-3/3); dry - slightly plastic; firm; vertical contact between dark brown (10YR-3/3) and red (2.5YR-4/6); moist - stiff - firm to hard; red (2.5YR-4/6); weak hydrocarbon odor	A 1338 J 5421 A 1339	24 / 15 24 / 18 24 / 16 24 / 19	0.1 0.1 30	cl
CLAYEY SAND - 80% very fine to fine grained sand; compact; red (2.5YR-4/6); moist - decrease in clay; increase in moisture content	A 1340 J 5422	24 / 17 24 / 7	4.6	sc
SAND - very fine to fine grained; loose; slightly silty; red (2.5YR-4/6); wet - no recovery at 16'		24 / 12		sp
SILTY SAND - 80% very fine to fine grained sand; compact; red (2.5YR-4/6): wet - no recovery at 18'		24 / 6		sm
SILTY CLAYEY SAND - very fine to fine grained sand; loose; soupy; red (2.5YR-4/6); wet - slightly clayey - compact; moist		24 / 24 24 / 24		sm

TOTAL DEPTH = 23.0 FEET

GEOPHYSICAL LOG (GAMMA)



GRAPHIC LOG / DEPTH IN FEET

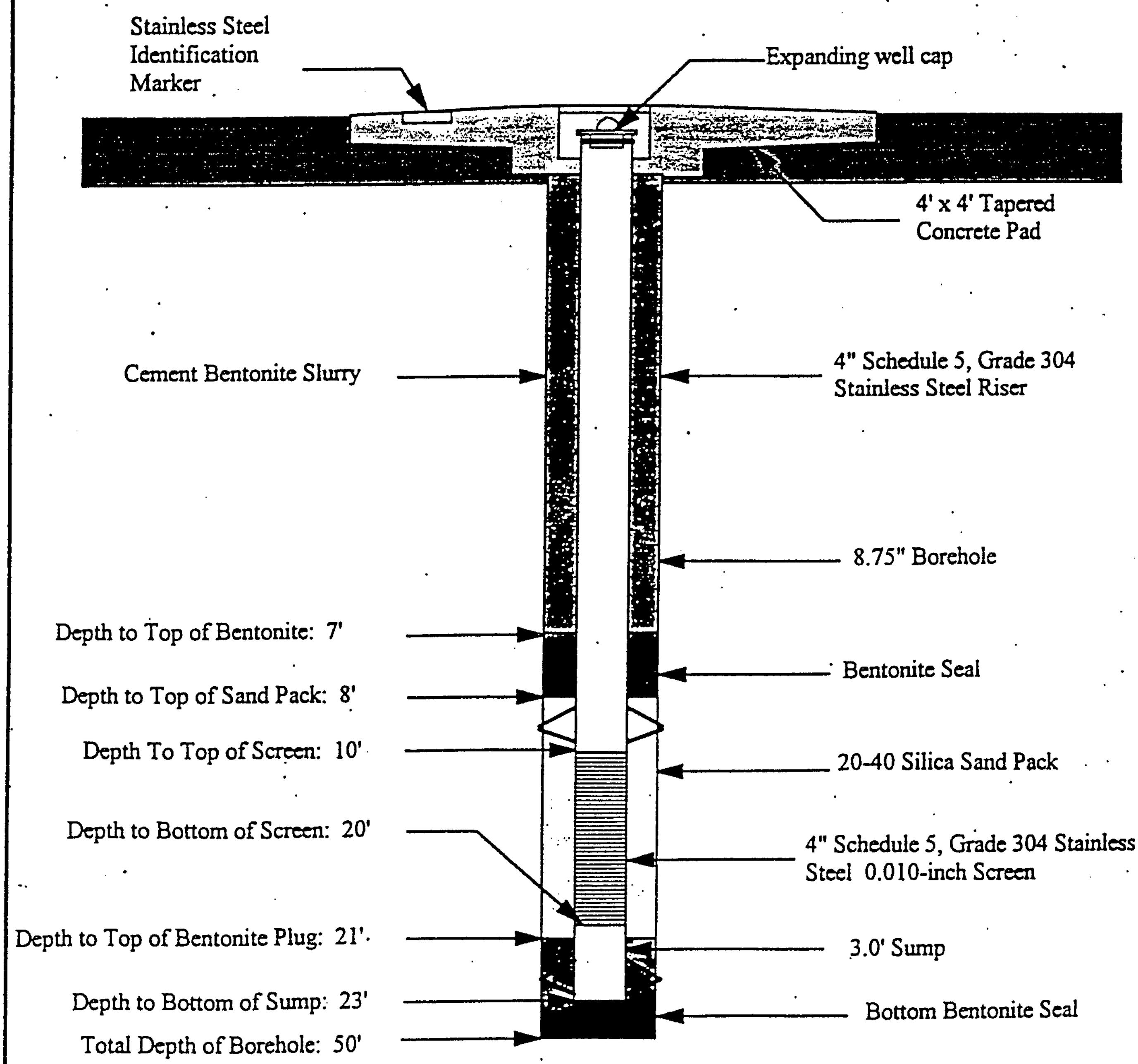


DRAFT BY	RPS 11/18/93	DRAFT CHK		PROJ. CHK		APPRV. BY		DWG. NO.	409802-A25 Sheet 1 of 1

WELL CONSTRUCTION SCHEMATIC

②

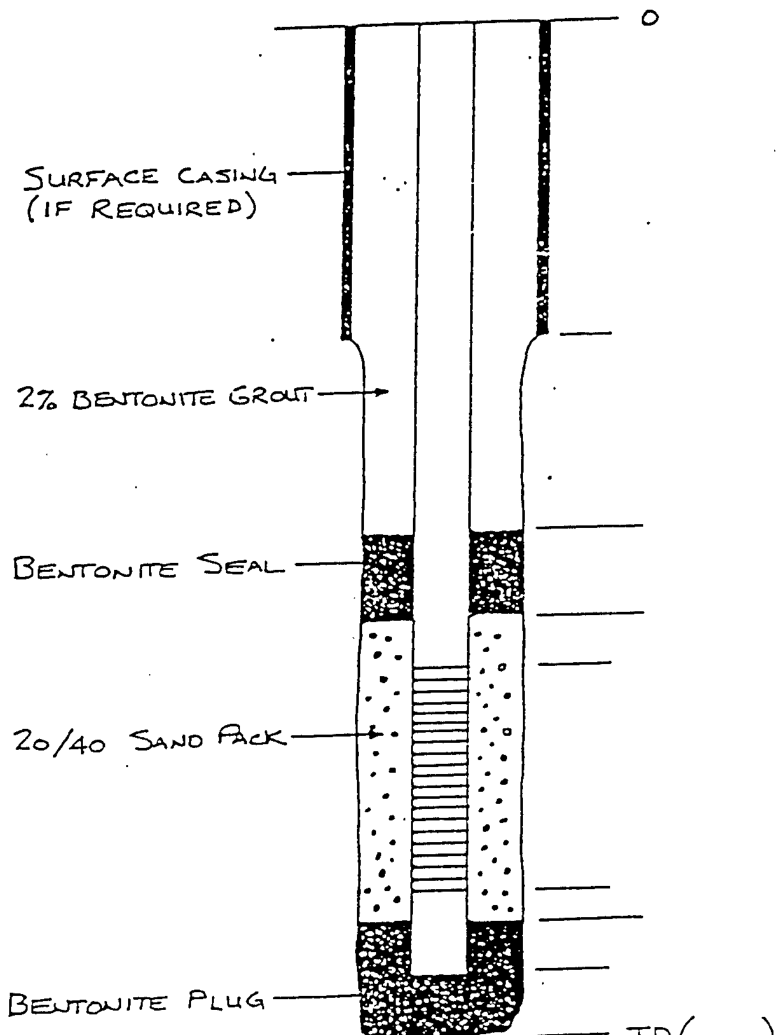
Client: Tinker Air Force Base	Well ID: **2-163B**
Location: TAFB, Oklahoma	Site: ST33
Contract No: F34650-94-D-0082/5003 (P & A 2)	Date 4-Inch Riser Set: 06/01/95
Contractor: Brown & Root Environmental	Drilling Method: Auger
Project Manager: David Parker	Ground Level Elev. (AMSL):
Project Geologist: James W. Roberts	Top of Csg. Elev. (AMSL):
Drlg Contractor: Associated Environmental, Inc.	Dedicated Pump: 2-inch Grundfos
Comments: Top Riser: 4" Schedule 40 PVC Casing. 1' thick top bentonite seal set.	



Drawing not to scale

< > Centralizers

Well ID	Recommended Construction Item	Depth	Comments
2-163B	Surface Casing		
	Inner Casing		
	Grout	0-7	
	Bentonite Seal (top)	7-8	
	Sand Pack	8-21	
	Bentonite Seal (bottom)	21-TD	
	Riser	0-10	
	Screen	10-20	
	Sump	20-23	



Log Received
9:00 Am 6-1-95

Well Design Deliver
9:20 Am 6-1-95

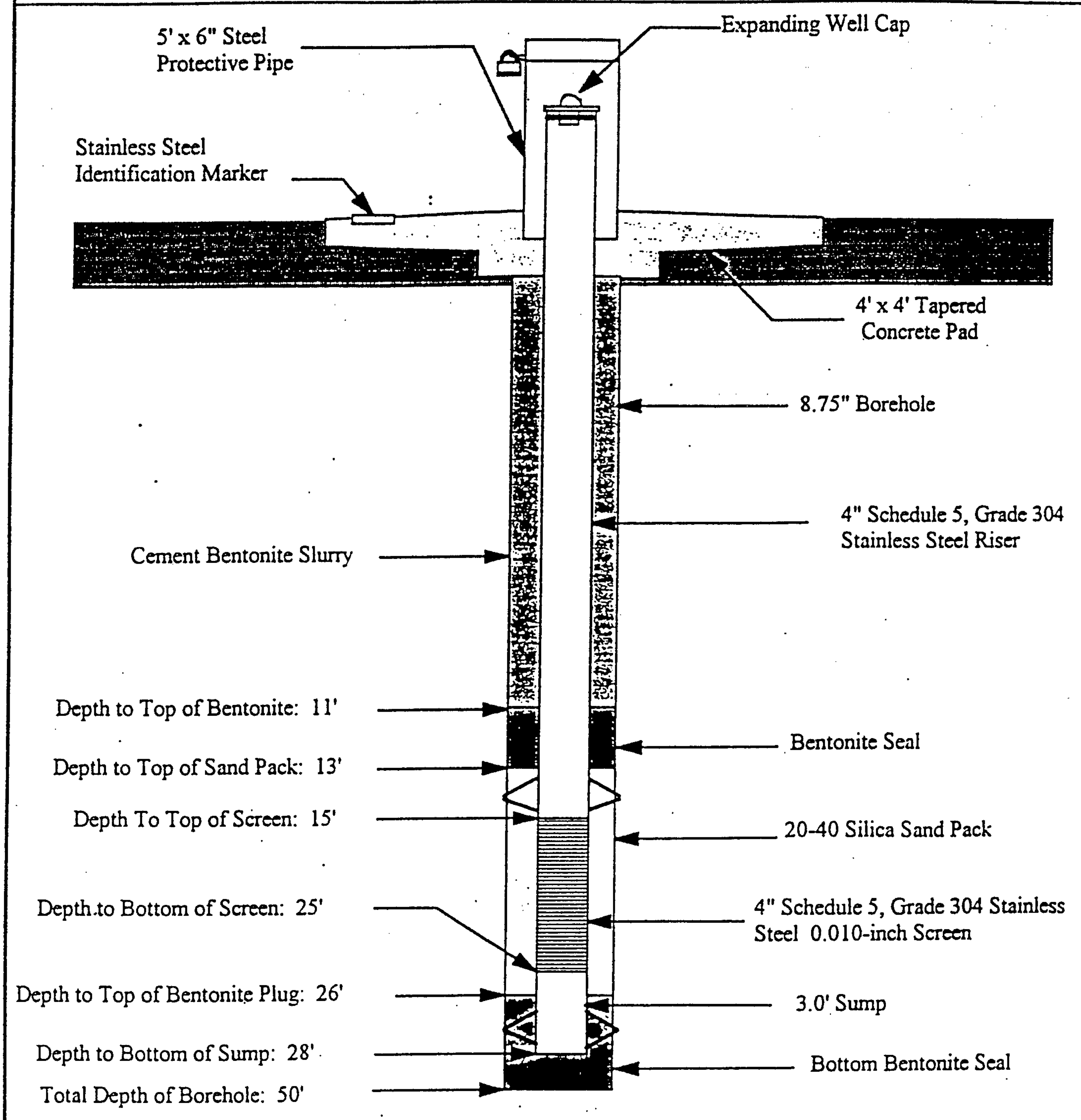
1 LOG RUN

2 LOG RUN

WELL CONSTRUCTION SCHEMATIC

(R)

Client: Tinker Air Force Base	Well ID: **2-164B**
Location: TAFB, Oklahoma	Site: ST33
Contract No: F34650-94-D-0082/5004 (P & A 3)	Date 4-Inch Riser Set: 06/02/95
Contractor: Brown & Root Environmental	Drilling Method: Auger
Project Manager: David Parker	Ground Level Elev. (AMSL): '
Project Geologist: James W. Roberts	Top of Csg. Elev. (AMSL): '
Drlg Contractor: Associated Environmental, Inc.	Dedicated Pump: 2-inch Grundfos
Comments: Top Riser: 4" Schedule 40 PVC Casing. 2' thick top seal set.	



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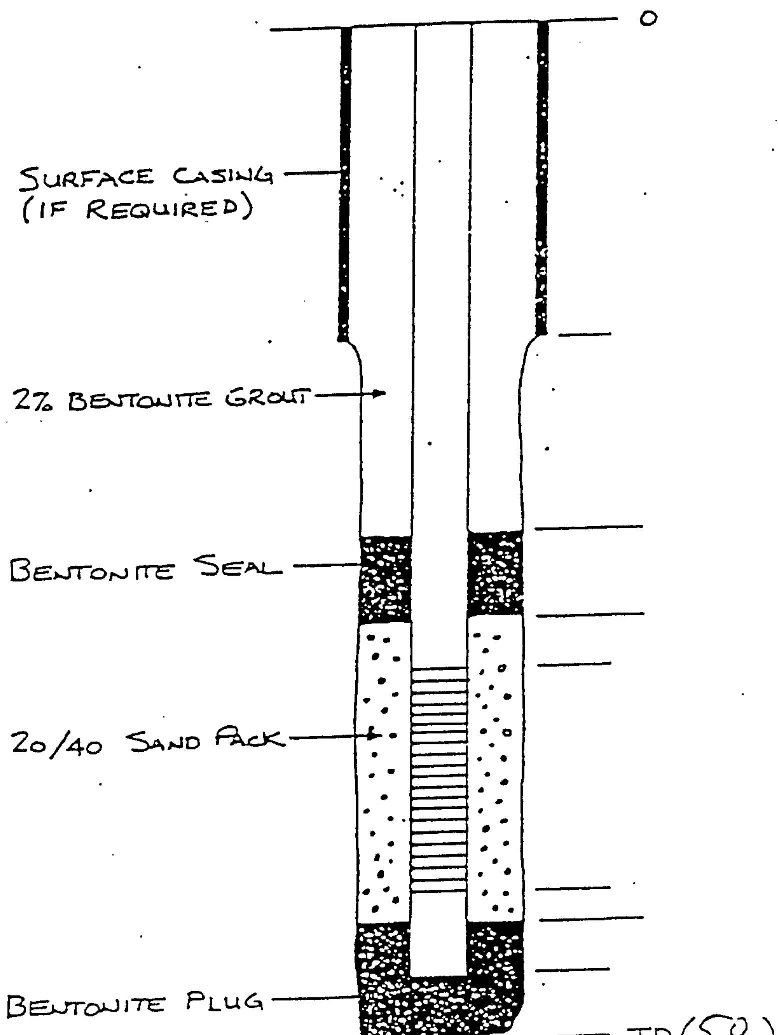
< > Centralizers

R

Well ID	Recommended Construction Item	Depth	Comments
2-164B	Surface Casing	—	
	Inner Casing	—	
	Grout	0 - 11	
	Bentonite Seal (top)	11 - 13	(2')
	Sand Pack	13 - 26	
	Bentonite Seal (bottom)	26 - TD	
	Riser	0-15	
	Screen	15·25	
	Sump	25·28	



Well Design Delivered 6-2-95 4:30

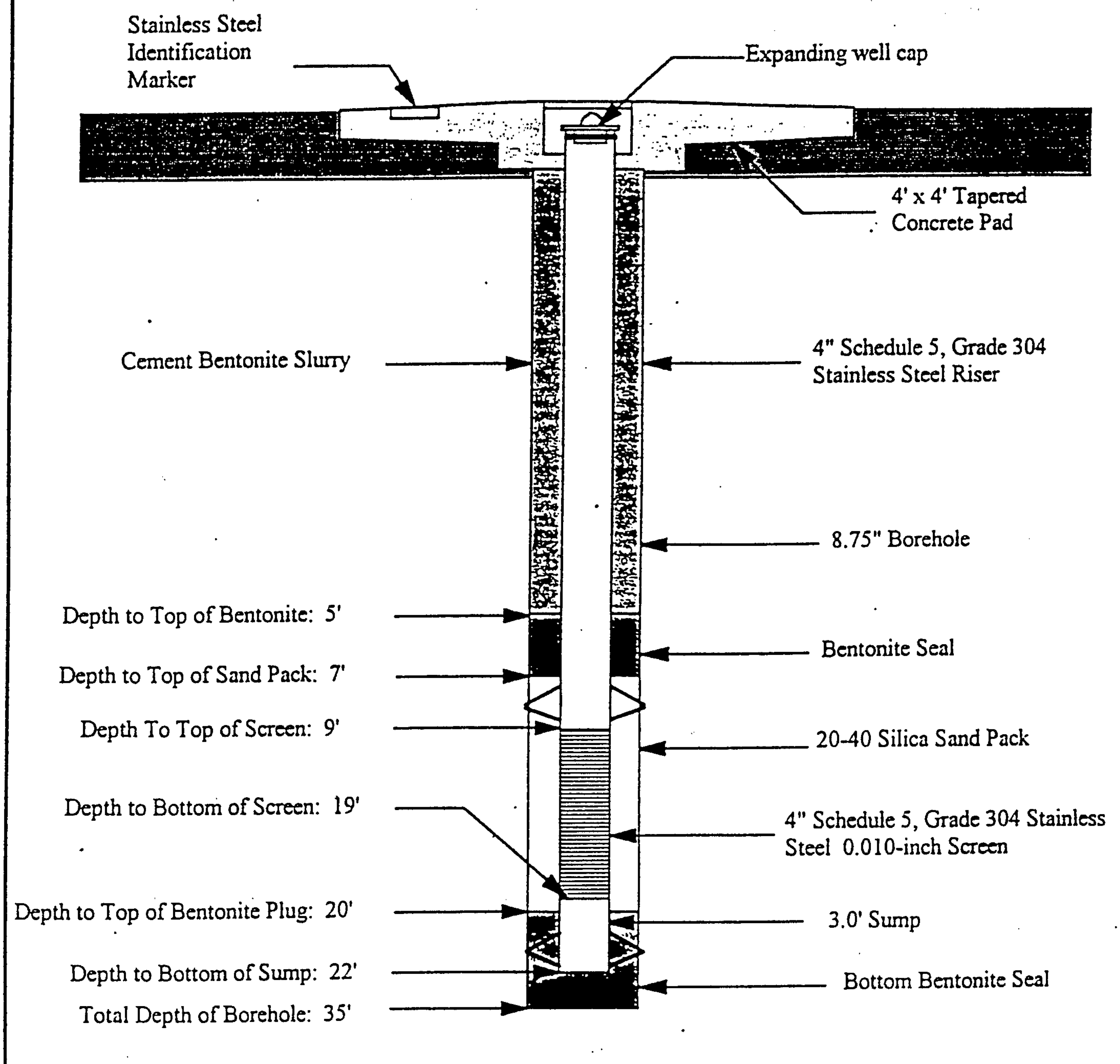
Log Received 6-2-95 4:10 _ _ _ _ 1 LOG RUN _ _ _ _ _

_ _ _ _ 2 LOG RUN _ _ _ _ _

_ _ _ _ _ _ _ _ _ _ _ _ _ _

WELL CONSTRUCTION SCHEMATIC

Client: Tinker Air Force Base	Well ID: **2-165B**
Location: TAFB, Oklahoma	Site: ST33
Contract No: F34650-94-D-0082/5003 (P & A 2)	Date 4-Inch Riser Set: 06/07/95
Contractor: Brown & Root Environmental	Drilling Method: Auger
Project Manager: David Parker	Ground Level Elev. (AMSL):
Project Geologist: James W. Roberts	Top of Csg. Elev. (AMSL):
Drlg Contractor: Associated Environmental, Inc.	Dedicated Pump: 2-inch Grundfos
Comments: 2' thick top bentonite seal set. Top Riser: 4" Schedule 40 PVC Casing.	



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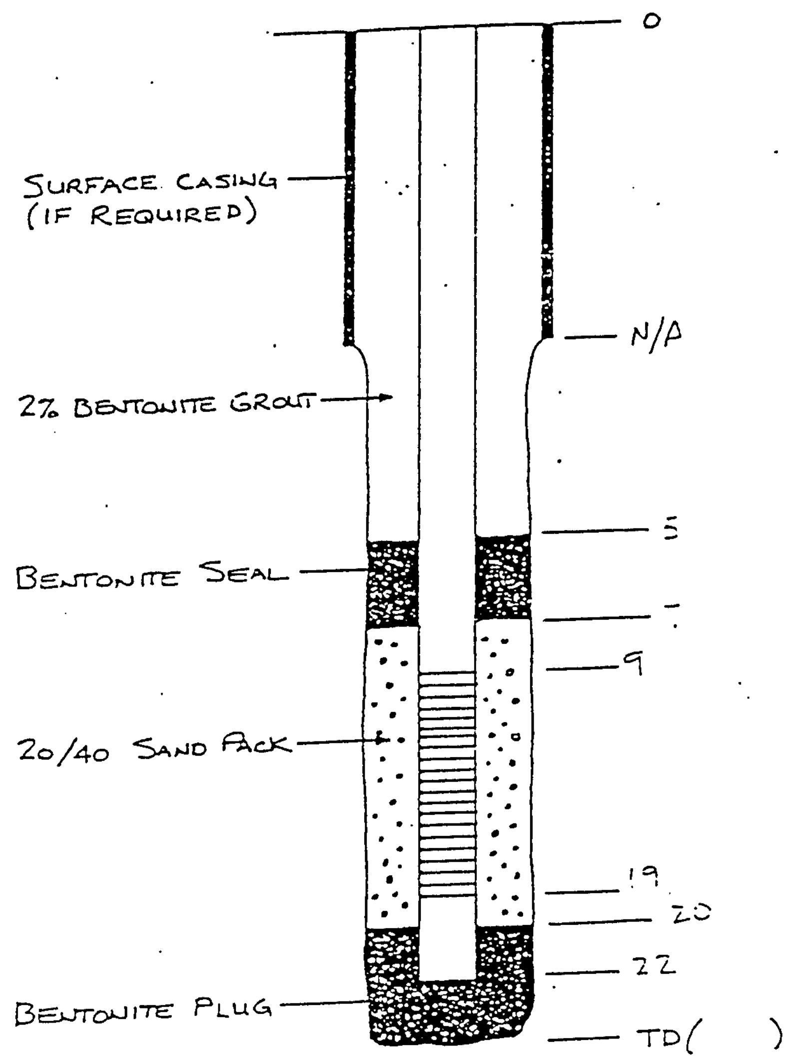
< > Centralizers

Well ID	Recommended Item	Construction Depth	Comments
2-165B	Surface Casing	—	
	Inner Casing	—	
	Grout	0-5	
	Bentonite Seal (top)	5-7	
	Sand Pack	7-20	
	Bentonite Seal (bottom)	20-TD	
	Riser	0-9	
	Screen	9-19	
	Sump	19-22	



Well Design Delivered
[illegible] [illegible]

Log Received
[illegible] [illegible]

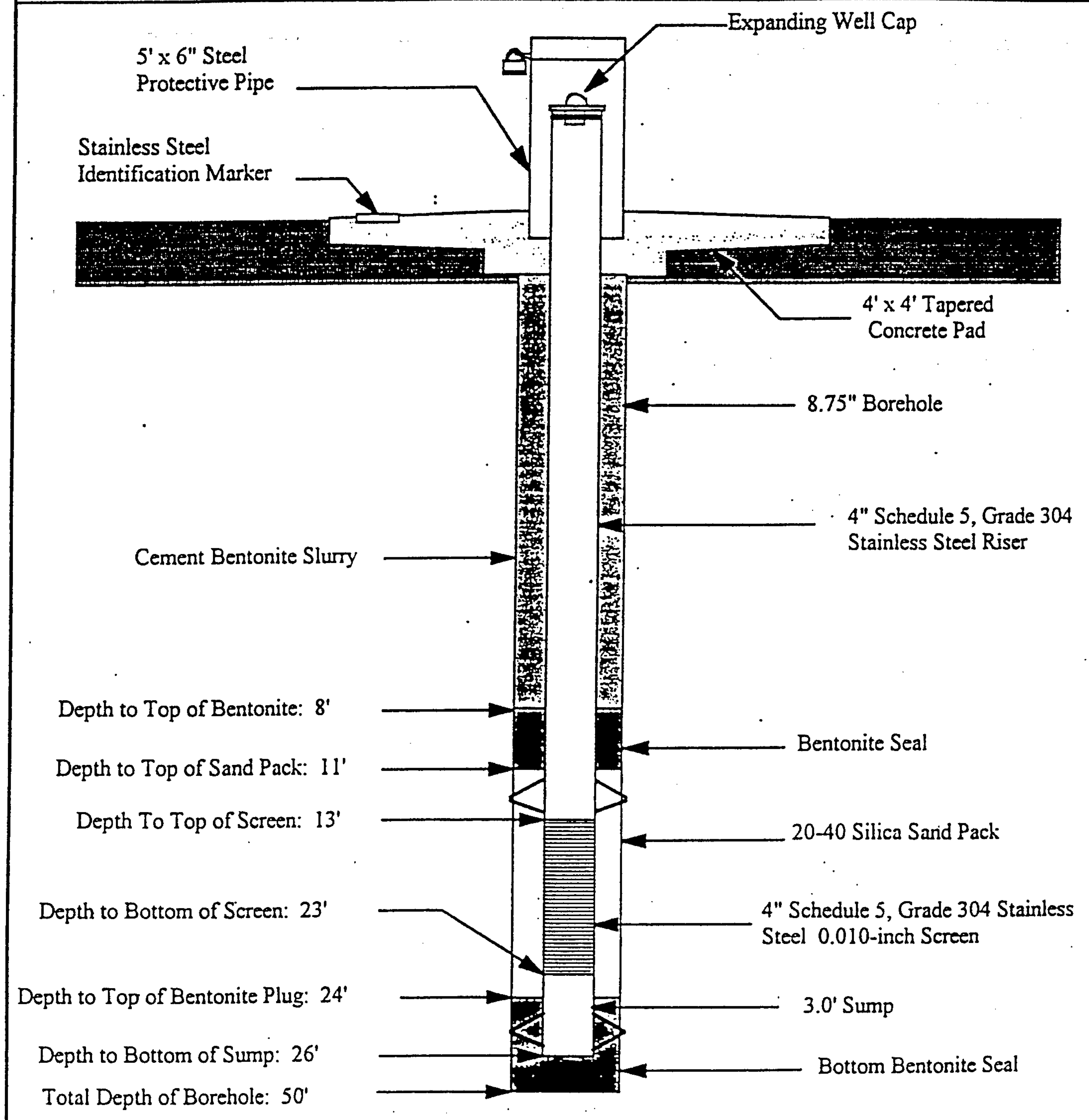
1 LOG RUN

2 LOG RUN

WELL CONSTRUCTION SCHEMATIC

(R)

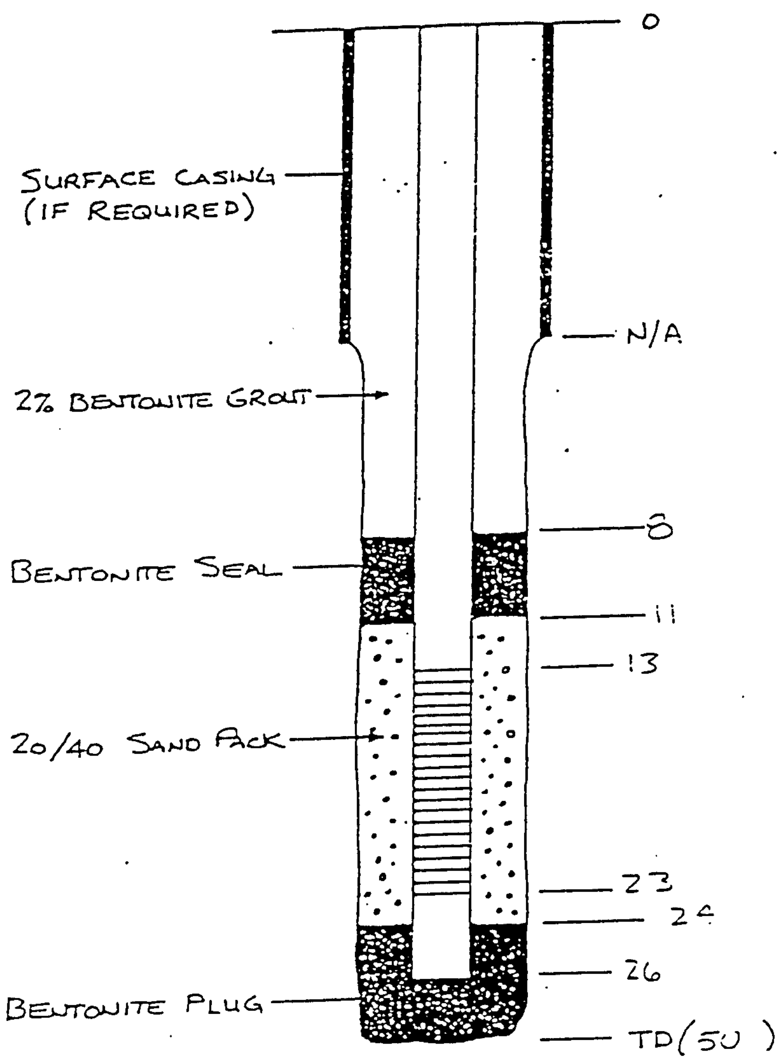
Client: Tinker Air Force Base	Well ID: 2-166B
Location: TAFB, Oklahoma	Site: ST33
Contract No: F34650-94-D-0082/5004 (P & A 3)	Date 4-Inch Riser Set: 06/07/95
Contractor: Brown & Root Environmental	Drilling Method: Auger
Project Manager: David Parker	Ground Level Elev. (AMSL): '
Project Geologist: James W. Roberts	Top of Csg. Elev. (AMSL): '
Drlg Contractor: Associated Environmental, Inc.	Dedicated Pump: 2-inch Grundfos
Comments: 3' thick top bentontite seal set. Top Riser: 4" Schedule 40 PVC Casing.	



Drawing not to scale

< > Centralizers

Well ID	Recommended Construction Item	Depth	Comments
Z-166E	Surface Casing	—	
	Inner Casing	—	
	Grout	0-8	
	Bentonite Seal (top)	8-11	
	Sand Pack	11-24	
	Bentonite Seal (bottom)	24-TD	
	Riser	0-13	
	Screen	13-23	
	Sump	23-26	



Log Received 6-6-95

Well Design Delivery 6-7-95 9:00 AM

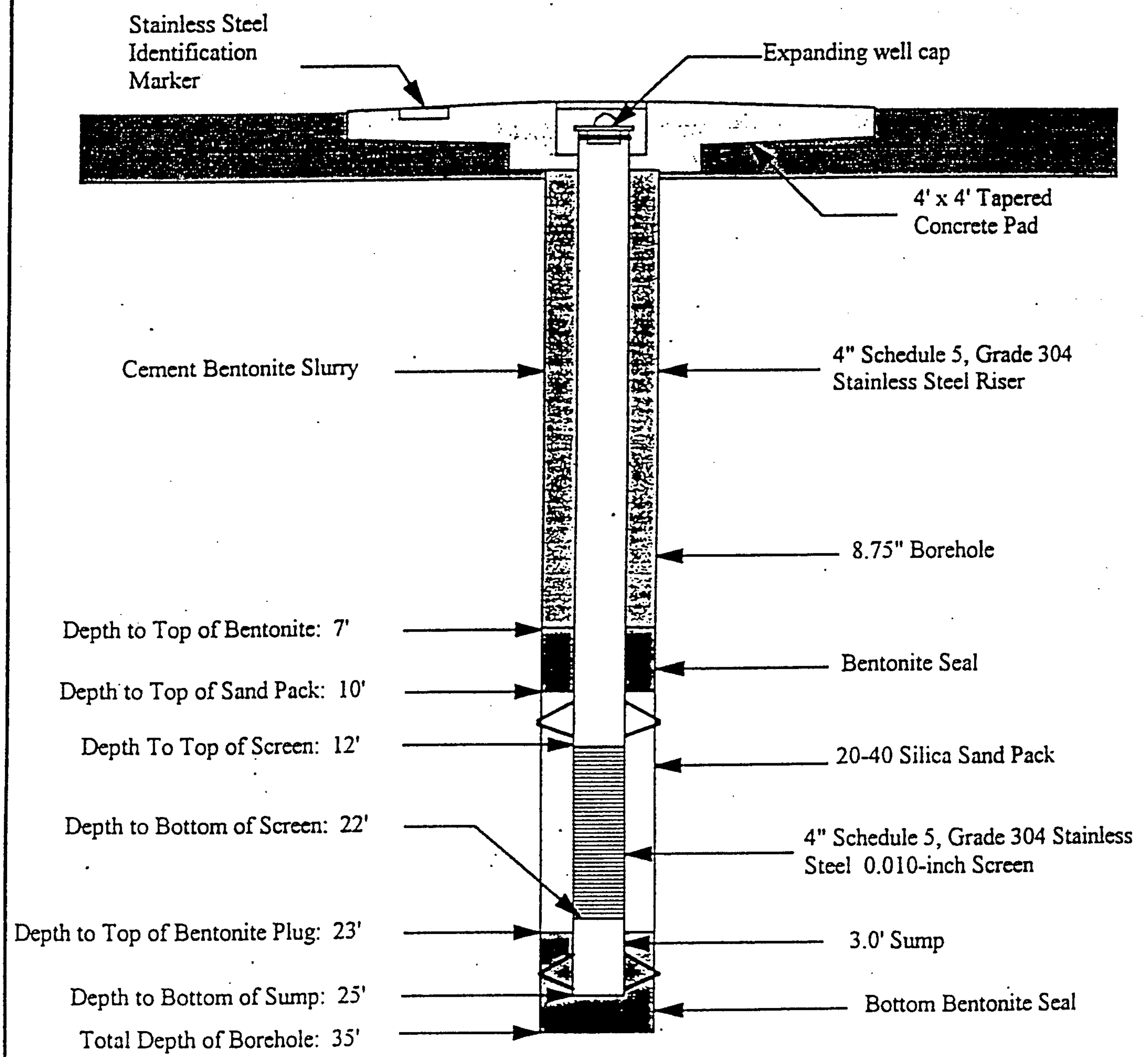
1 LOG RUN

2 LOG RUN

WELL CONSTRUCTION SCHEMATIC

Client: Tinker Air Force Base	Well ID: **2-173B**
Location: TAFB, Oklahoma	Site: ST33
Contract No: F34650-94-D-0082/5003 (P & A 2)	Date 4-Inch Riser Set: 06/14/95
Contractor: Brown & Root Environmental	Drilling Method: Auger
Project Manager: David Parker	Ground Level Elev. (AMSL):
Project Geologist: James W. Roberts	Top of Csg. Elev. (AMSL):
Drlg Contractor: Associated Environmental, Inc.	Dedicated Pump: 2-inch Grundfos

Comments: Top Riser: 4" Schedule 40 PVC Casing. 3' thick top bentonie seal set.



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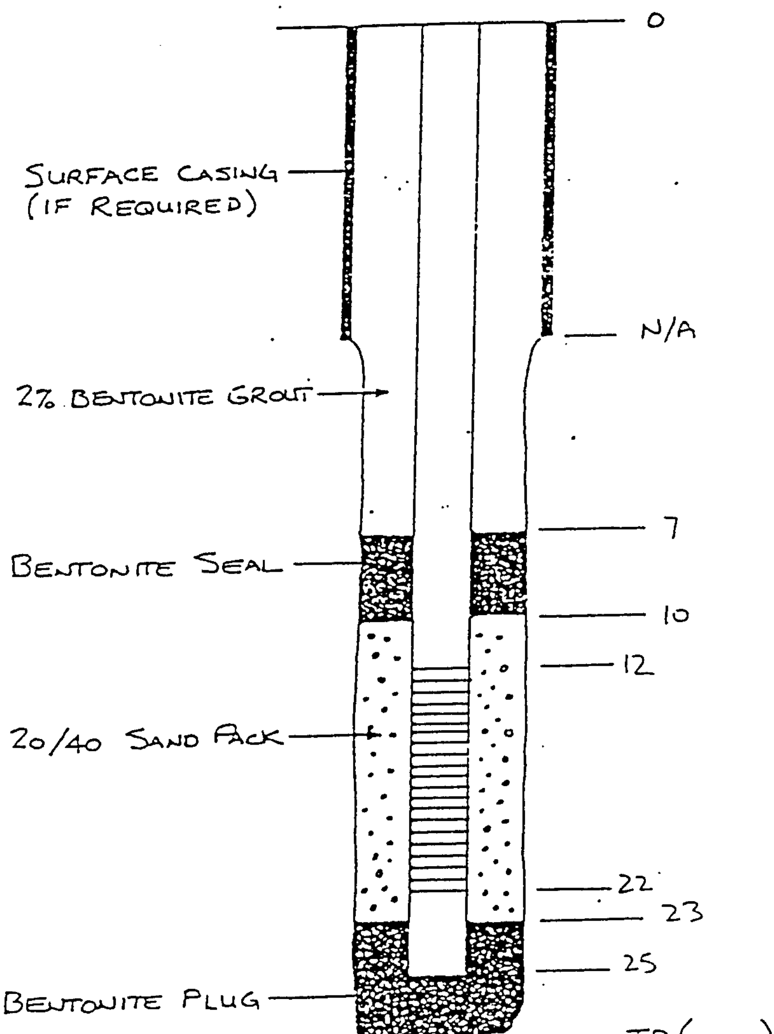
< > Centralizers

2

Well ID	Recommended Construction Item	Depth	Comments
2-173B	Surface Casing	—	
	Inner Casing	—	
	Grout	0-7	
	Bentonite Seal (top)	7-10	
	Sand Pack	10-23	
	Bentonite Seal (bottom)	23-TD	
	Riser	0-12	
	Screen	12-22	
	Sump	22-25	



Log Received
5-14-95 3:45

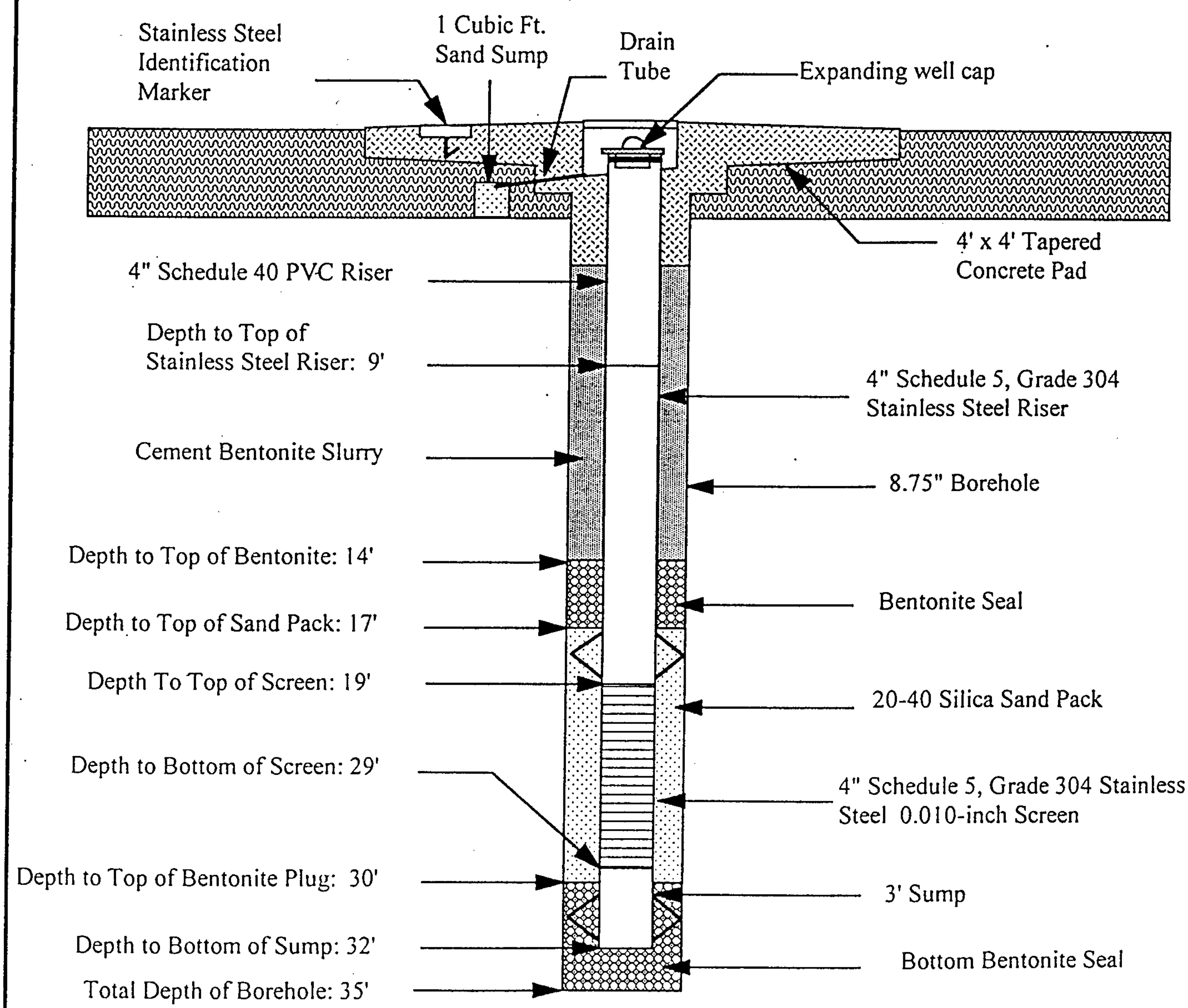
1 LOG RUN

2 LOG RUN

Well Design Delivery
5-14-95 3:45

WELL CONSTRUCTION SCHEMATIC

Client: Tinker Air Force Base	Well ID: **2-264B**
Location: TAFB, Oklahoma	Site: ST33
Contract No: F34650-94-D-0082/5017 (P&A #4)	Date 4-Inch Riser Set: 06/12/96
Contractor: Brown & Root Environmental	Ground Level Elevation (AMSL): 1,235.08'
Project Manager: David Parker	Top of Casing Elevation (AMSL): 1,234.86'
Project Geologist: Steve Kelly	Northing Coordinate: 158,467.86'
Drilling Contractor: Associated Environmental, Inc.	Easting Coordinate: 2,179,427.90'
Drilling Method: Hollow Stem Auger	Permanent Monuments Used in Survey: SE53, PR11
Dedicated Pump: 2-inch Grundfos	Legal Description: NW/4 Section 15, T11N, R2W
Comments: 3' thick top bentonite seal set.	

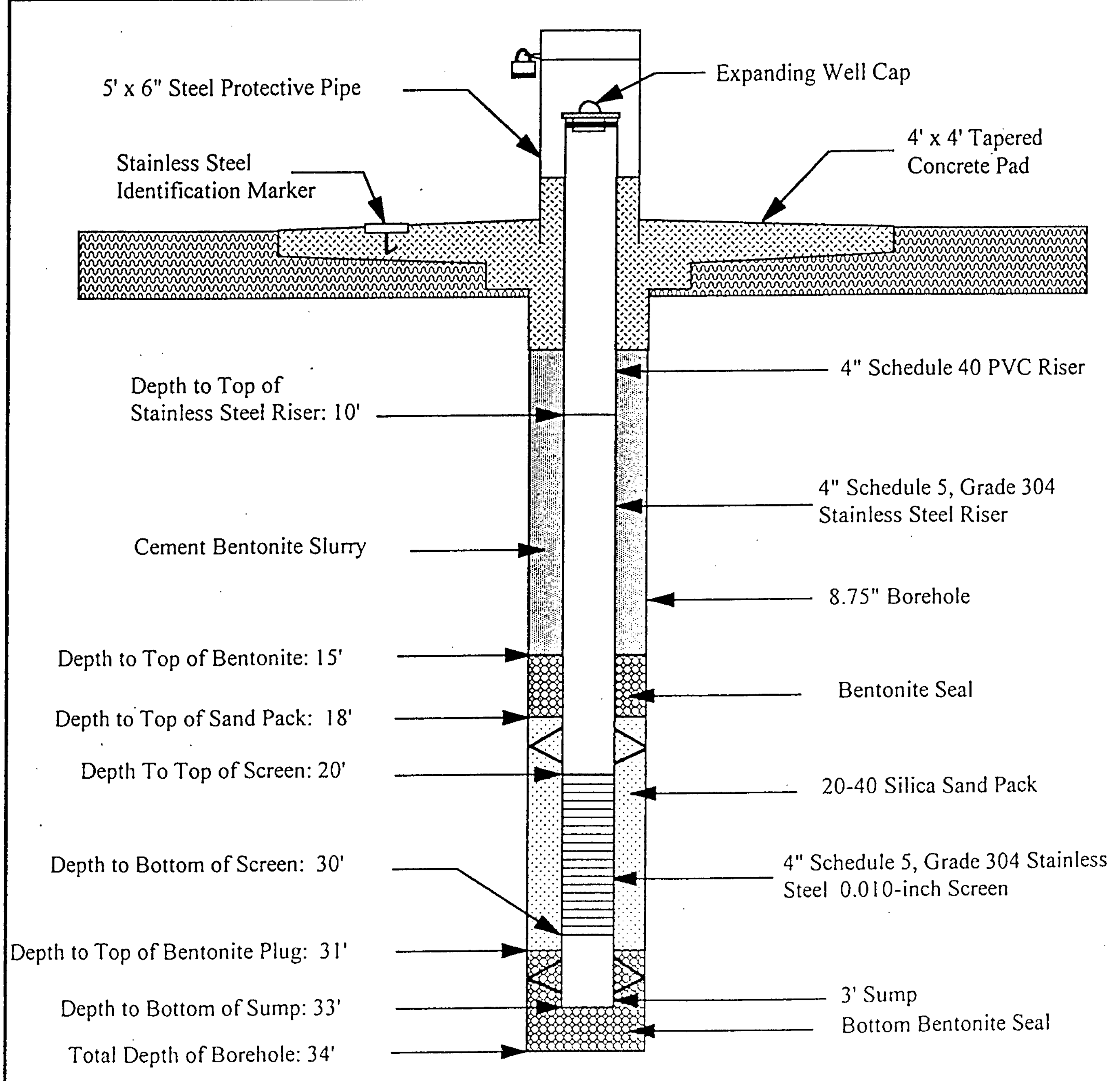


Drawing not to scale

< > Centralizers

WELL CONSTRUCTION SCHEMATIC

Client: Tinker Air Force Base	Well ID: **2-265B**
Location: TAFB, Oklahoma	Site: ST33
Contract No: F34650-94-D-0082/5017 (P&A #4)	Date 4-Inch Riser Set: 06/12/96
Contractor: Brown & Root Environmental	Ground Level Elevation (AMSL): 1,234.13'
Project Manager: David Parker	Top of Casing Elevation (AMSL): 1,236.63'
Project Geologist: Steve Kelly	Northing Coordinate: 158,291.51'
Drilling Contractor: Associated Environmental, Inc.	Easting Coordinate: 2,179,373.38'
Drilling Method: Hollow Stem Auger	Permanent Monuments used in Survey: SE53, PR11
Dedicated Pump: 2-inch Grundfos	Legal Description: NW/4 Section 15 T11N, R2W
Comments: 3' thick top bentonite seal set.	



Drawing not to scale

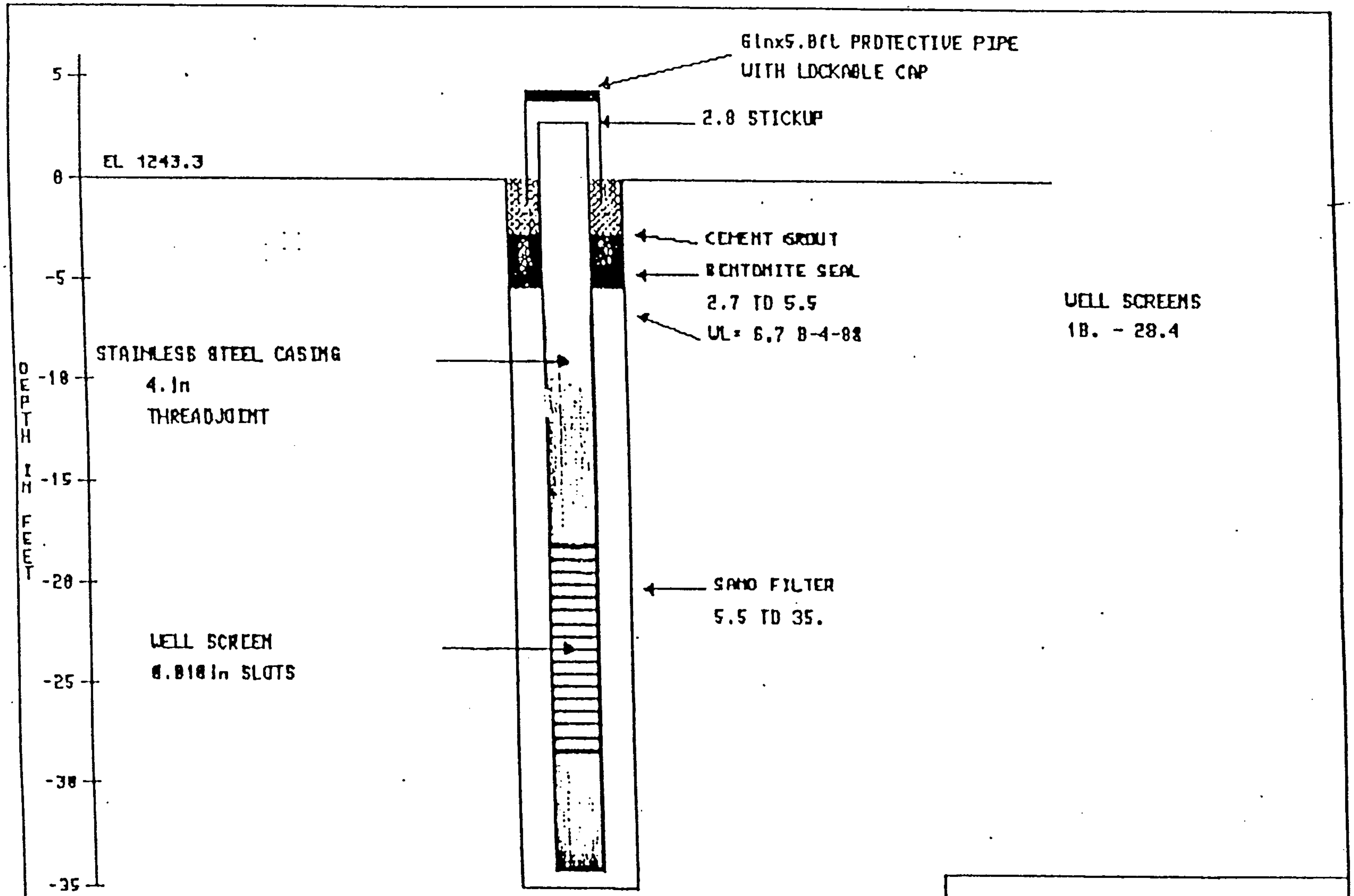
< > Centralizers

DRILLING LOG	DIVISION SOUTHWEST	INSTALLATION TINKER AFB	SHEET 1 OF 1 SHEETS

1. PROJECT	PERIMETER MONITORING WELLS
2. LOCATION (Coordinates or Station)	158485.40 2180809.30
3. DRILLING AGENCY	TULSA DISTRICT
4. HOLE NO. (As shown on drawing title and file number)	MW-70
5. NAME OF DRILLER	JAMES WYATT
6. DIRECTION OF HOLE	[X] VERTICAL [ ] INCLINED ______ DEG. FROM VERT.
7. THICKNESS OF OVERBURDEN	8.0
8. DEPTH DRILLED INTO ROCK	27.0
9. TOTAL DEPTH OF HOLE	35.0
10. SIZE AND TYPE OF BIT	6"A 9.5"RB
11. DATUM FOR ELEVATION SHOWN (TBM or MSL)	MSL
12. MANUFACTURER'S DESIGNATION OF DRILL	CME
13. TOTAL NO. OF OVERBURDEN SAMPLES TAKEN	DISTURBED 0 / UNDISTURBED 0
14. TOTAL NUMBER CORE BOXES	0
15. ELEVATION GROUND WATER	7.0' (5 NOV 87)
16. DATE HOLE	STARTED 10/29/1987 / COMPLETED 10/29/1987
17. ELEVATION TOP OF HOLE	1243.3
18. TOTAL CORE RECOVERY FOR BORING	0.0 %
19. SIGNATURE OF INSPECTOR	CARL NARDIN

ELEVATION a	DEPTH b	LEGEND c	CLASSIFICATION OF MATERIALS (Description) d	% CORE RECOVERY e	BOX OR SAMPLE NO. f	REMARKS (Drilling time, water loss, depth of weathering, etc., if significant) g
1233.1			CLAY (CL) (0.0 – 0.4) TOPSOIL, DK-BROWN, DRY			AUGERED W/6" BIT TO WATER @ 25.0', ROCKBIT TO 35.0' WITH 9 1/2" BIT.
1232.5			CONCRETE () (0.4 – 1.0)			
	2		CLAY (CL) (1.0 – 4.0) SILTY, SOFT, LOW PLAST., RED-BROWN, SL. MOIST			MEASURED WATER LEVEL AT 7.0' ON 5 NOV 87.
1229.5	4					SET 37.0' OF 4" STAINLESS STEEL CASING WITH SCREEN FROM 28.2 TO 17.8' AND A 5.8' SUMP. SAND FILTER TO 5.5', SEAL TO 2.7'.
	6		SAND (SC) (4.0 – 8.0) CLAYEY, V. FINE, LOOSE, GRAY-BROWN, SL. MOIST			BAILED INSIDE PIPE AND FLUSHED WITH FRESH WATER.
1225.5	8					
▽	10		SANDSTONE (SS) (8.0 – 35.0) SHALEY, LOOSELY CEMENTED, V. FINE, RED-BROWN, OCCASIONALLY SPECKLED W/ GREEN-GRAY, SL. MOIST 8.0' TO 15.0' WET @ 15.0'			
	12					
	14					
	16					
	18					
1223.3	20		BOTTOM OF HOLE AT 35.0'			

ENG FORM 1836 MAR 71 PREVIOUS EDITIONS ARE OBSOLETE. (TRANSLUCENT) | PROJECT PERIMETER MONITORING WELLS | HOLE NO. MW-70



NOTE: INSTALLATION IS SET IN PERCHED WATER TABLE

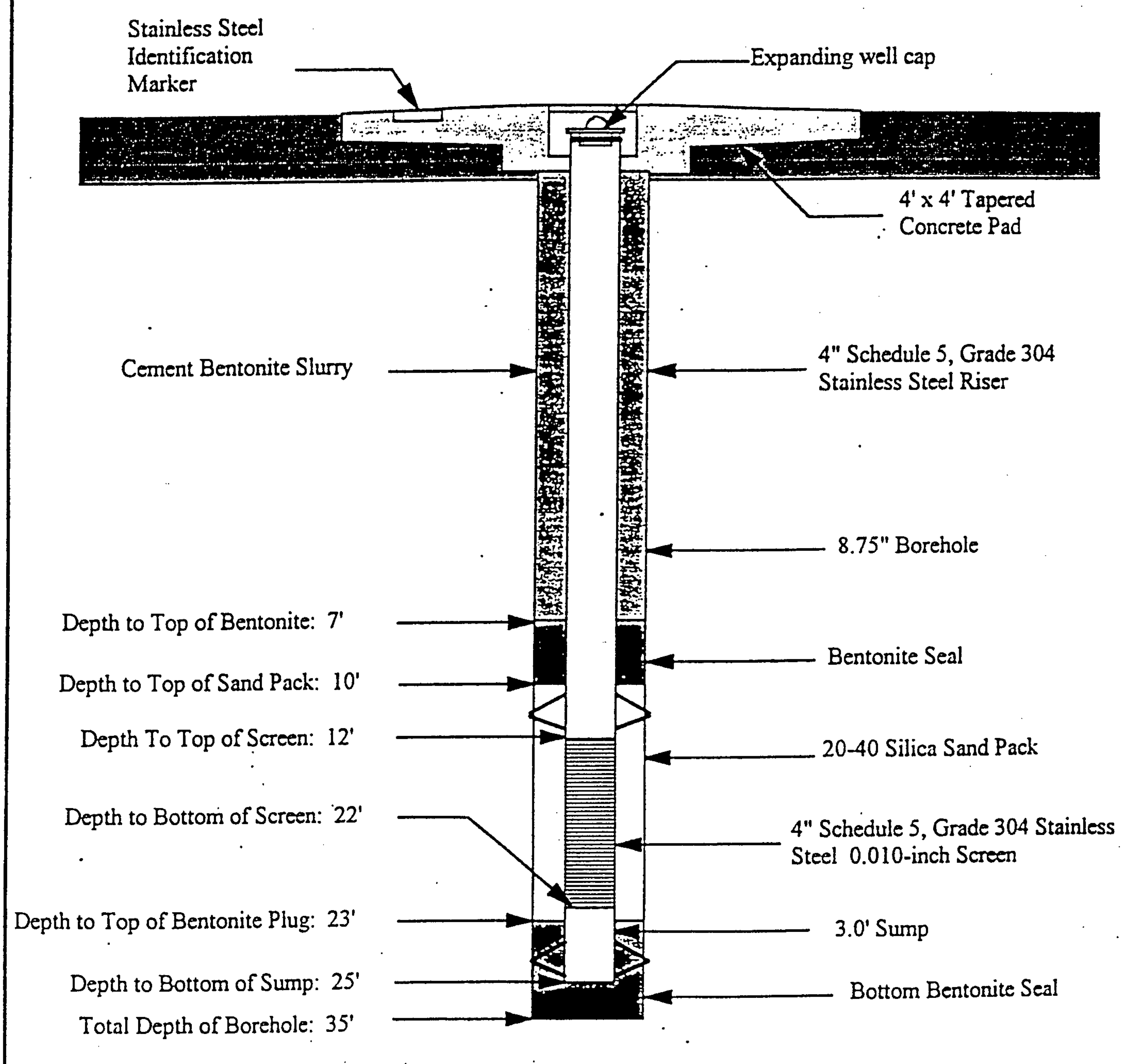
TAFB PERIMETER WELLS
MONITORING WELL 70 7C
FIGURE

2

WELL CONSTRUCTION SCHEMATIC

Client: Tinker Air Force Base	Well ID: **2-146B**
Location: TAFB, Oklahoma	Site: ST33
Contract No: F34650-94-D-0082/5003 (P & A 2)	Date 4-Inch Riser Set: 06/13/95
Contractor: Brown & Root Environmental	Drilling Method: Mud Rotary
Project Manager: David Parker	Ground Level Elev. (AMSL):
Project Geologist: James W. Roberts	Top of Csg. Elev. (AMSL):
Drlg Contractor: Associated Environmental, Inc.	Dedicated Pump: 2-inch Grundfos

Comments: Top Riser: 4" Schedule 40 PVC Casing. 3' thick top bentonite seal set.

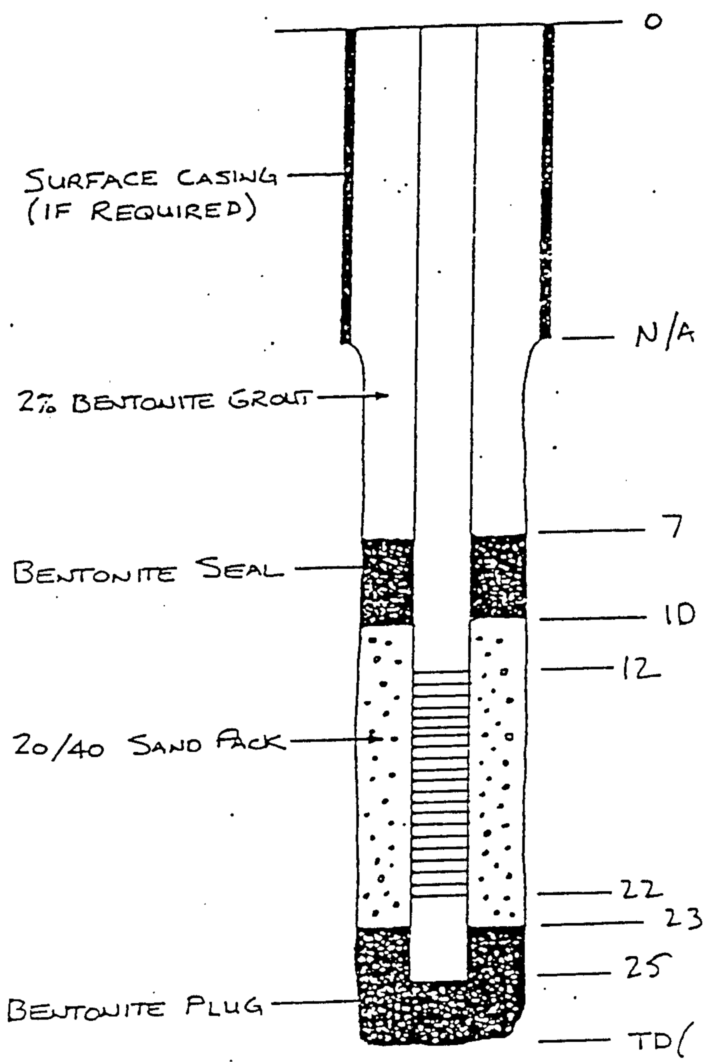


Drawing not to scale

< > Centralizers

R

Well ID	Recommended Construction Item	Construction Depth	Comments
2-146B	Surface Casing	—	
	Inner Casing	—	
	Grout	0-7	
	Bentonite Seal (top)	7-10	
	Sand Pack	10-23	
	Bentonite Seal (bottom)	23-TD	
	Riser	0-12	
	Screen	12-22	
	Sump	22-25	



Well Design Delivery
6-14-95 3:45

Log Received
6-14-95 3:21

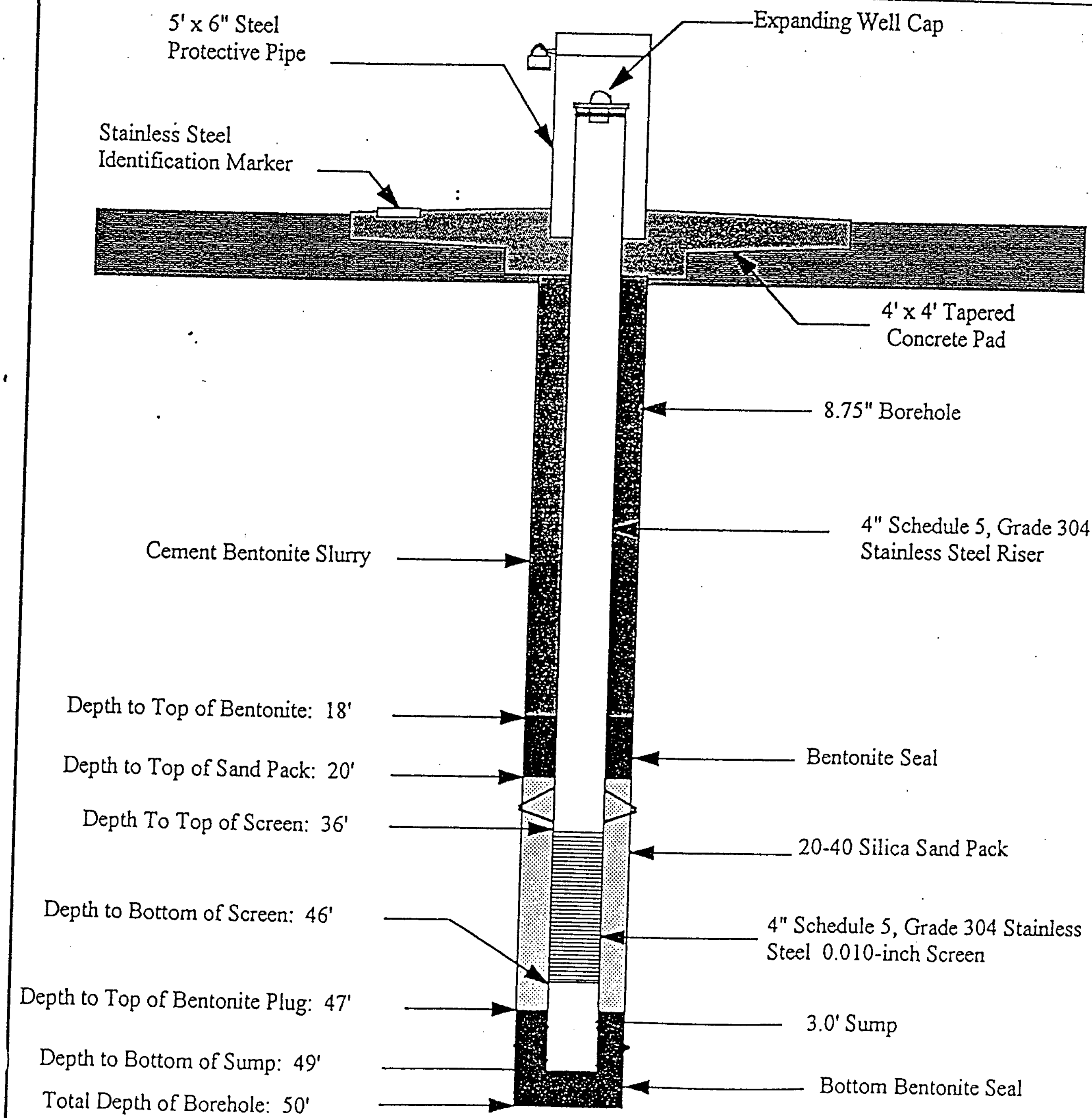
1 LOG RUN

2 LOG RUN

WELL CONSTRUCTION SCHEMATIC

Client: Tinker Air Force Base	Well ID: 2-147B
Location: TAFB, Oklahoma	Site: PRM
Contract No: F34650-94-D-0082/5004 (P & A 3)	Date 4-Inch Riser Set: 02/03/95
Contractor: Brown & Root Environmental	Drilling Method: Auger
Project Manager: David Parker	Ground Level Elev. (AMSL): 1268.63'
Project Geologist: James W. Roberts	Top of Csg. Elev. (AMSL): 1271.83'
Drlg Contractor: Associated Environmental, Inc.	Dedicated Pump: 2-inch Grundfos

Comments: Top Riser: 4" Schedule 40 PVC Riser Casing. 2' thick top seal. Top of sand set 16' above screen.

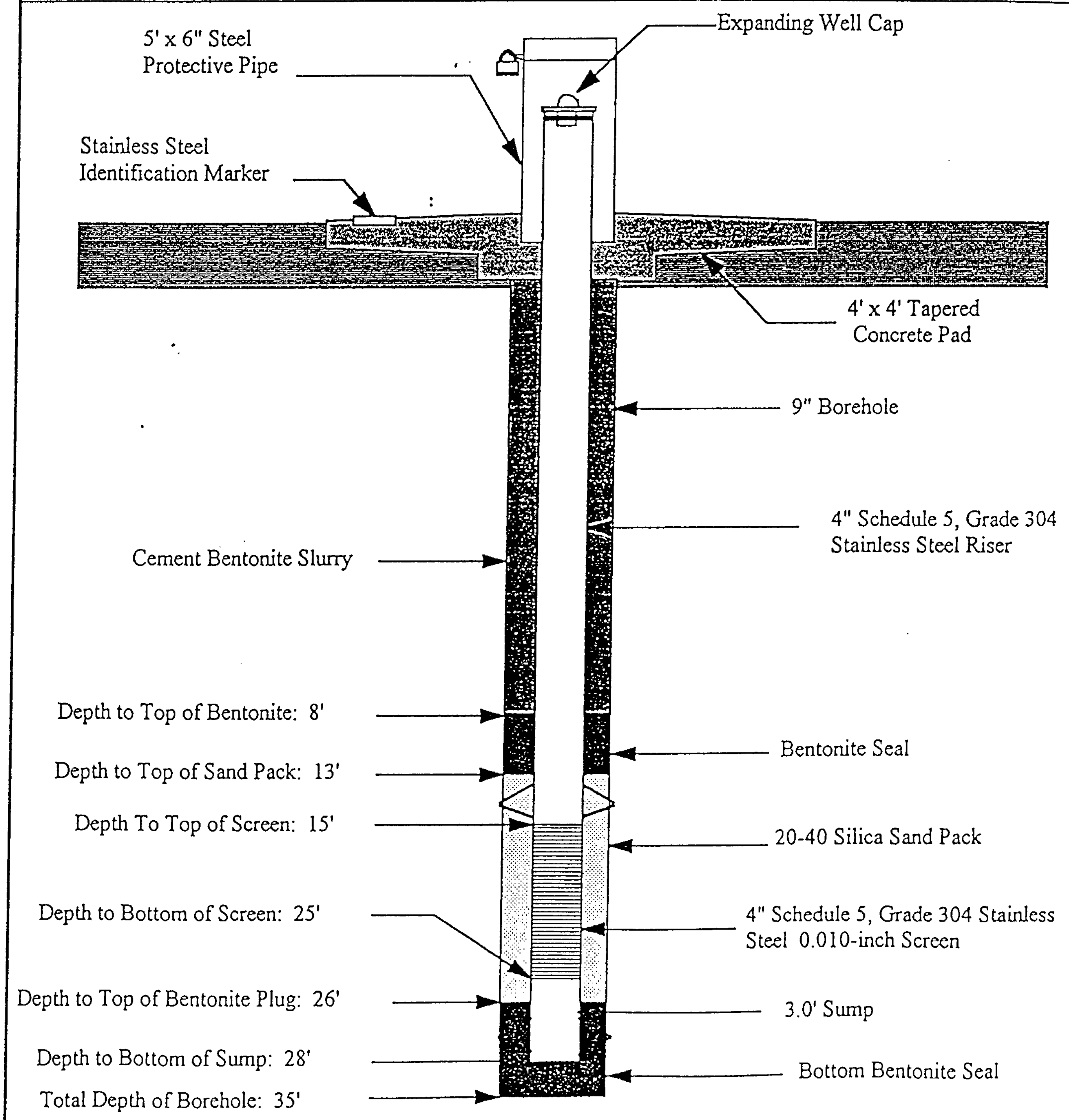


Drawing not to scale

< > Centralizers

WELL CONSTRUCTION SCHEMATIC

Client: Tinker Air Force Base	Well ID: 2-148B
Location: TAFB, Oklahoma	Site: PRM
Contract No: F34650-94-D-0082/5004 (P & A 3)	Date 4-Inch Riser Set: 05/20/95
Contractor: Brown & Root Environmental	Drilling Method: Auger
Project Manager: David Parker	Ground Level Elev. (AMSL): 1247.46'
Project Geologist: James W. Roberts	Top of Csg. Elev. (AMSL): 1250.12'
Drlg Contractor: Associated Environmental, Inc.	Dedicated Pump: 2-inch Grundfos
Comments:	

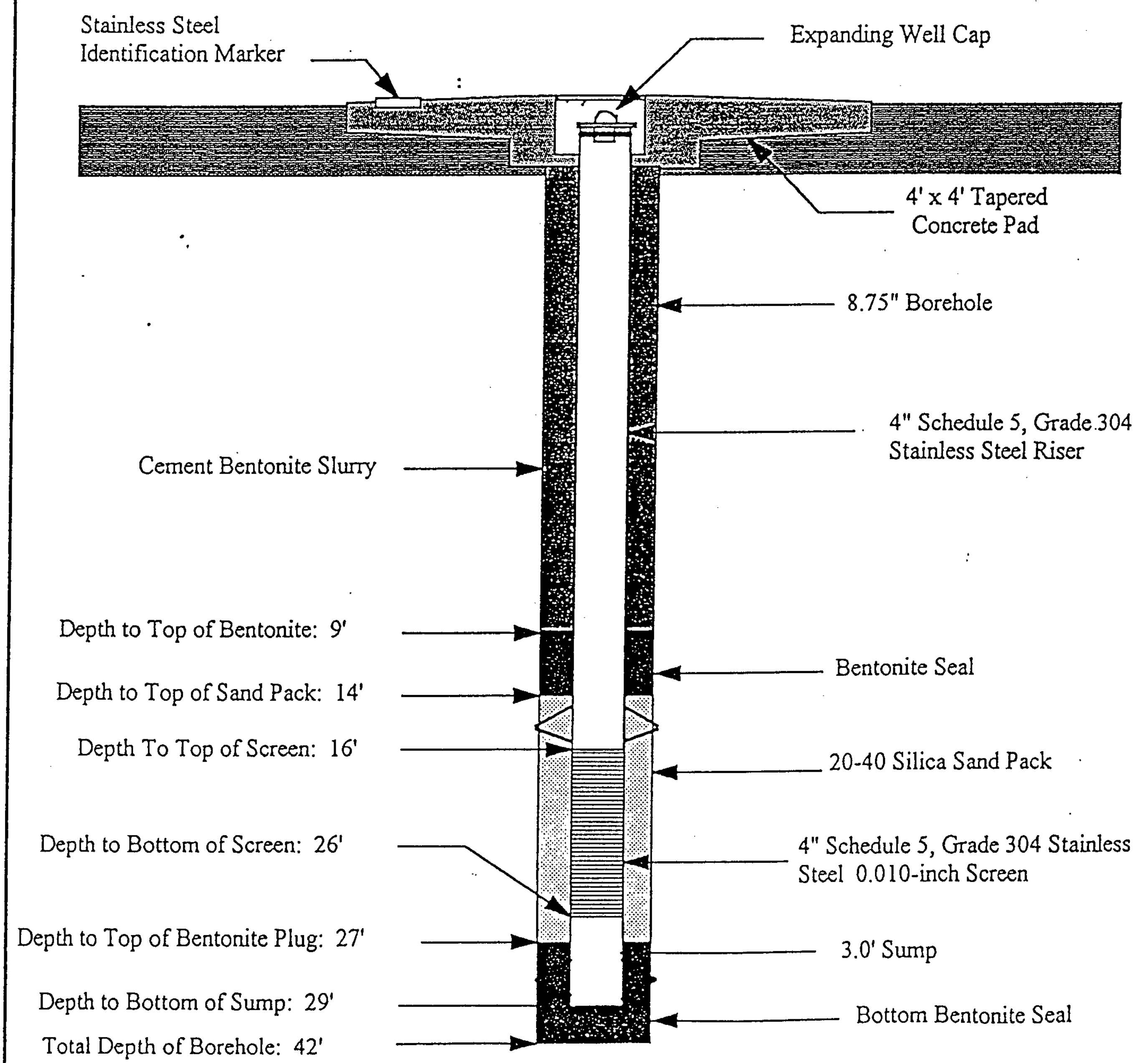


Drawing not to scale

< > Centralizers

WELL CONSTRUCTION SCHEMATIC

Client: Tinker Air Force Base	Well ID: 2-149B
Location: TAFB, Oklahoma	Site: PRM
Contract No: F34650-94-D-0082/5004 (P & A 3)	Date 4-Inch Riser Set: 06/07/95
Contractor: Brown & Root Environmental	Drilling Method: Auger
Project Manager: David Parker	Ground Level Elev. (AMSL): 1237.08'
Project Geologist: James W. Roberts	Top of Csg. Elev. (AMSL): 1236.55'
Drlg Contractor: Associated Environmental, Inc.	Dedicated Pump: 2-inch Grundfos
Comments: Top Riser: 4" Schedule 40 PVC Casing.	



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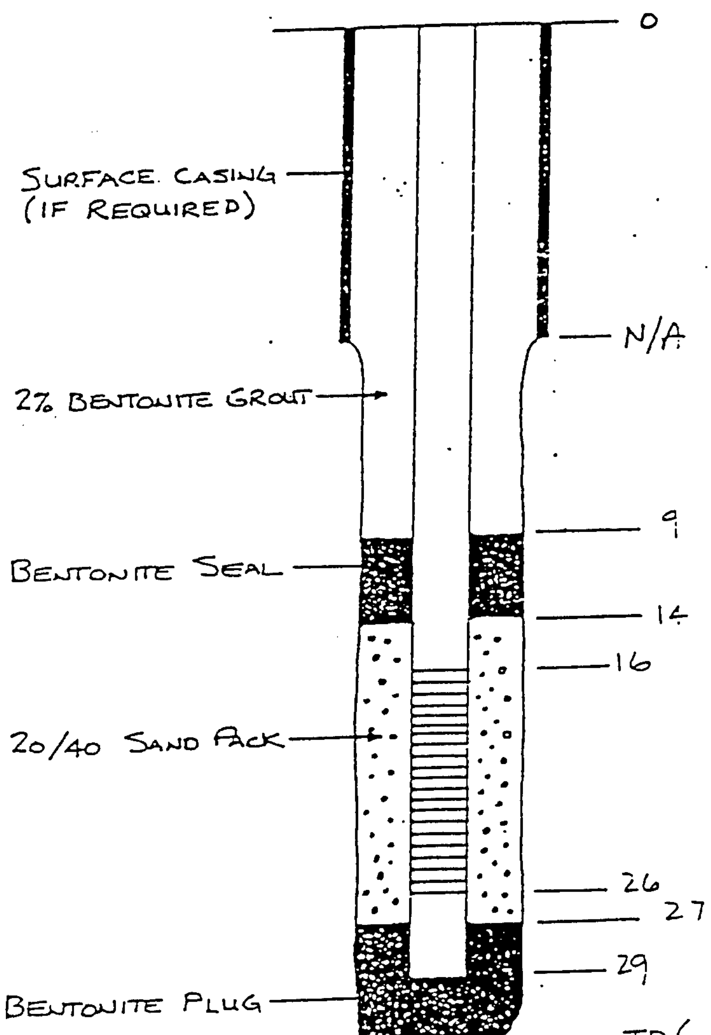
< > Centralizers

Well ID	Recommended Construction Item	Depth	Comments
Z-149B	Surface Casing	—	
	Inner Casing	—	
	Grout	0-9	
	Bentonite Seal (top)	9-14	
	Sand Pack	14-27	
	Bentonite Seal (bottom)	27-TD	
	Riser	0-16	
	Screen	16-26	
	Sump	26-29	



Well Design Delivery

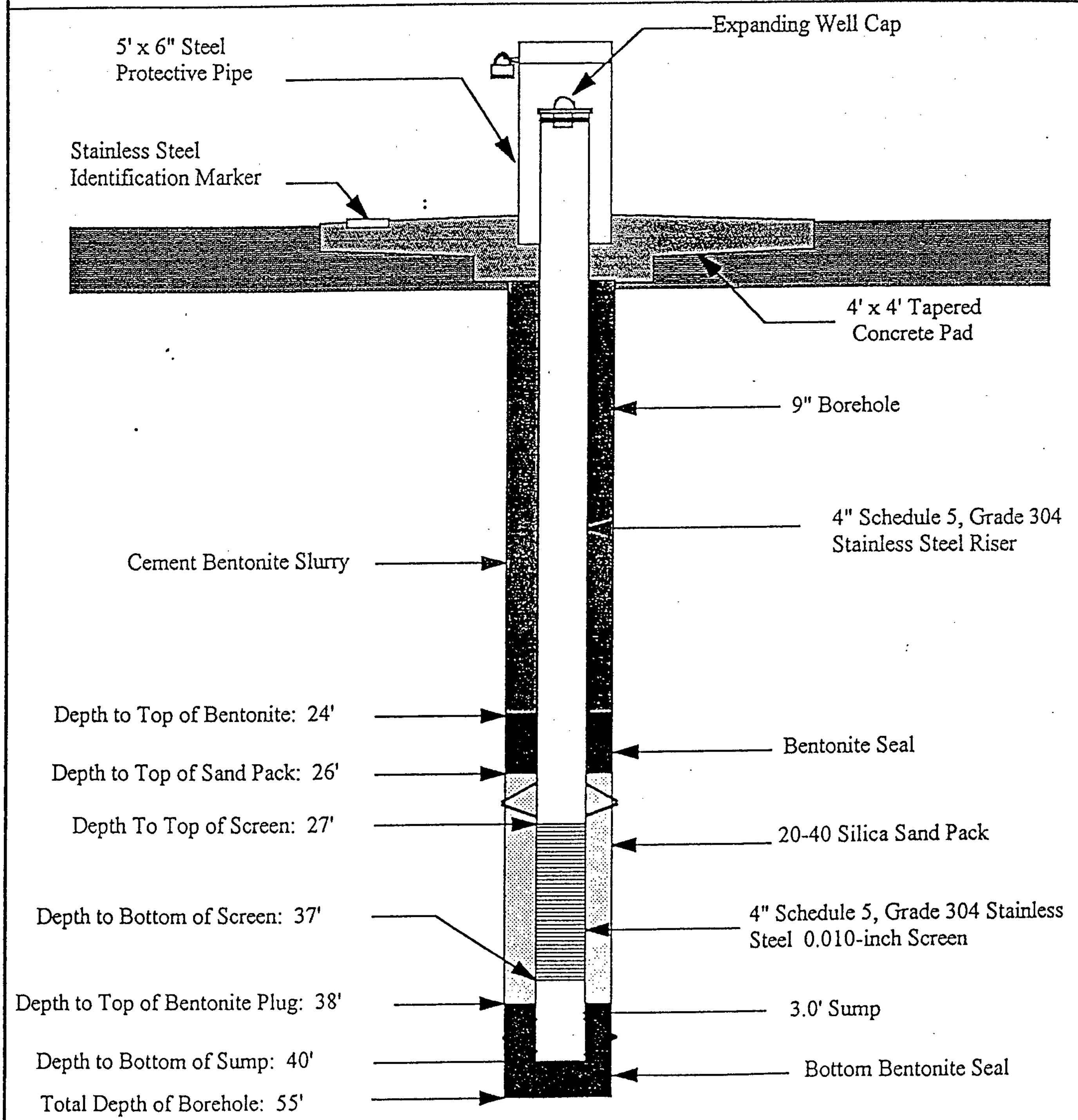
Log Received

1 LOG RUN

2 LOG RUN

WELL CONSTRUCTION SCHEMATIC

Client: Tinker Air Force Base	Well ID: **2-150B**
Location: TAFB, Oklahoma	Site: PRM
Contract No: F34650-94-D-0082/5004 (P & A 3)	Date 4-Inch Riser Set: 05/10/95
Contractor: Brown & Root Environmental	Drilling Method: Auger
Project Manager: David Parker	Ground Level Elev. (AMSL): 1231.40'
Project Geologist: James W. Roberts	Top of Csg. Elev. (AMSL): 1234.03'
Drlg Contractor: Associated Environmental, Inc.	Dedicated Pump: 2-inch Grundfos
Comments: Top Riser: 4" Schedule 40 PVC Casing. 2' thick top seal set. Top of sand placed 1' above screen.	



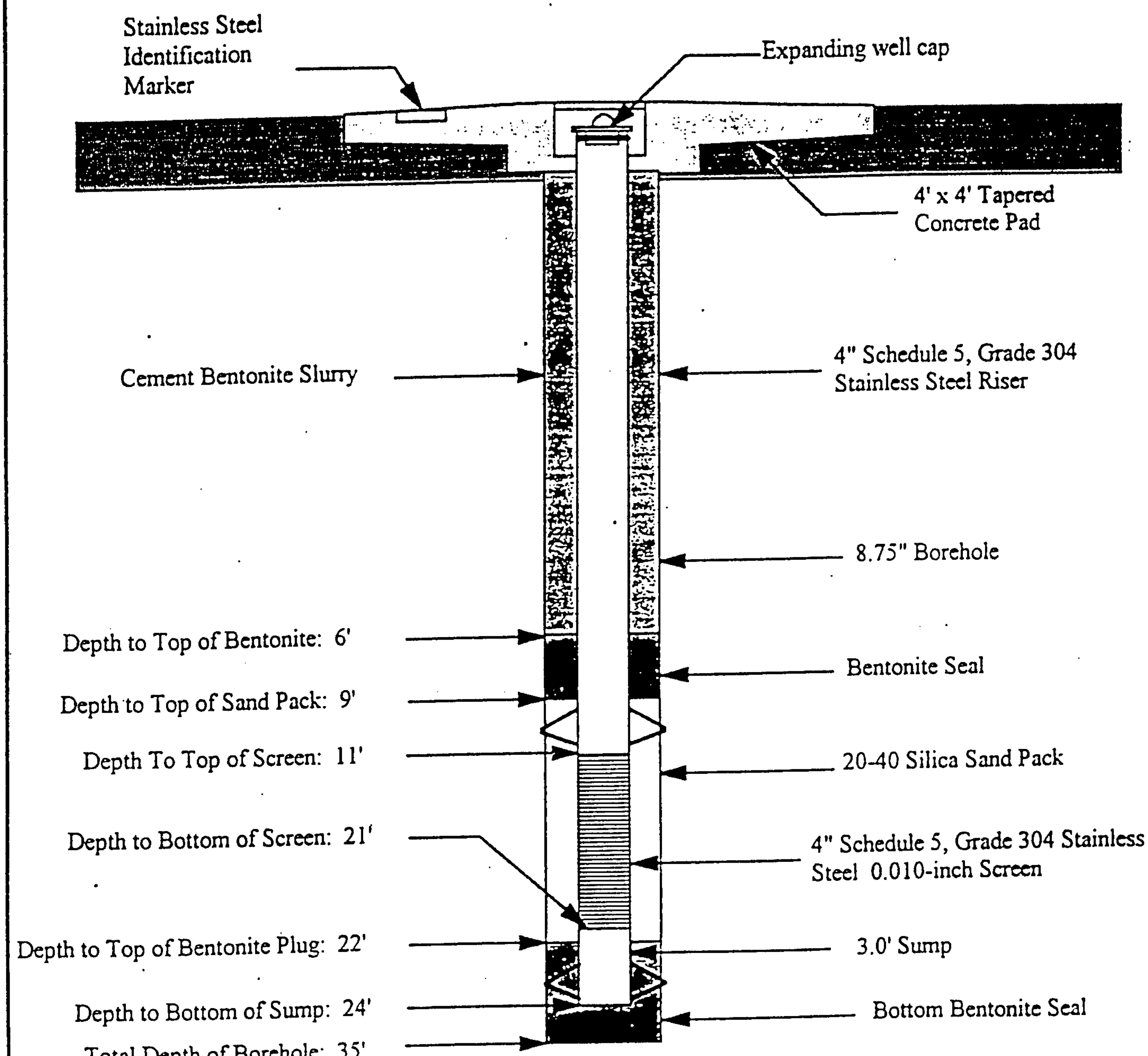
Drawing not to scale

< > Centralizers

WELL CONSTRUCTION SCHEMATIC (2)

Client: Tinker Air Force Base	Well ID: **2-145B**
Location: TAFB, Oklahoma	Site: ST33
Contract No: F34650-94-D-0082/5003 (P & A 2)	Date 4-Inch Riser Set: 06/14/95
Contractor: Brown & Root Environmental	Drilling Method: Auger
Project Manager: David Parker	Ground Level Elev. (AMSL):
Project Geologist: James W. Roberts	Top of Csg. Elev. (AMSL):
Drlg Contractor: Associated Environmental, Inc.	Dedicated Pump: 2-inch Grundfos

Comments: Top Riser: 4" Schedule 40 PVC Casing. 3' thick top bentonie seal set.



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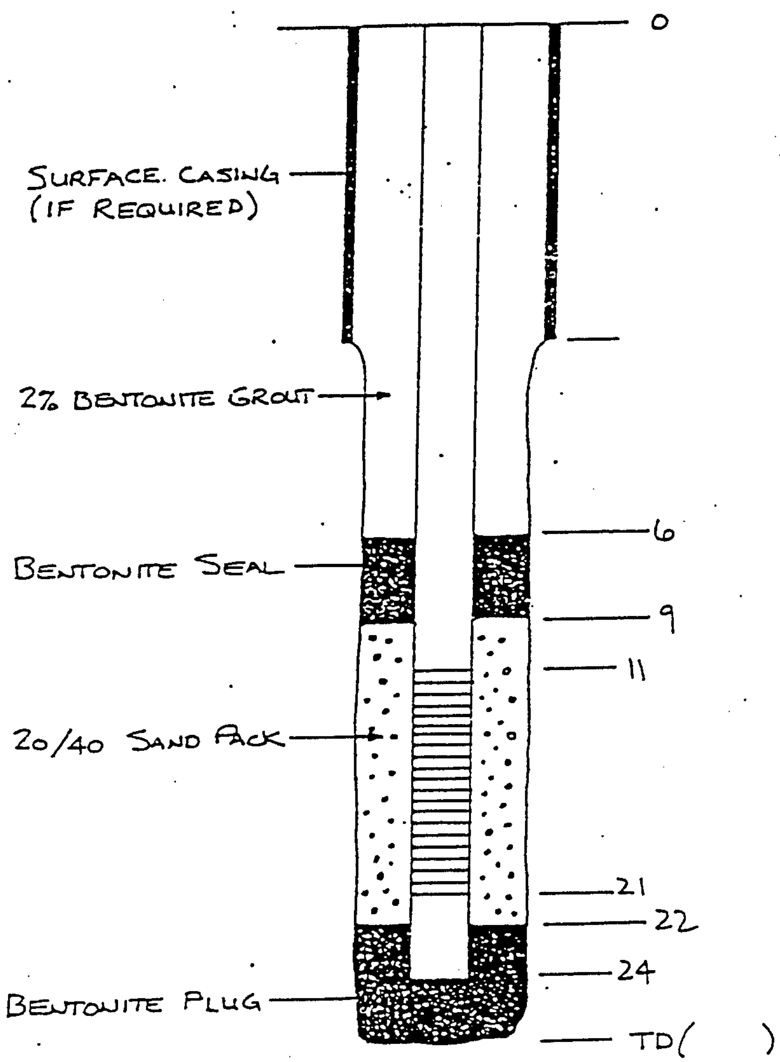
< > Centralizers

R

Well ID	Recommended Item	Construction Depth	Comments
Z-145B	Surface Casing	—	
	Inner Casing	—	
	Grout	0-6	
	Bentonite Seal (top)	6-9	
	Sand Pack	9-22	
	Bentonite Seal (bottom)	22-TD	
	Riser	0-11	
	Screen	11-21	
	Sump	21-24	



Log Received 6-14-95

1 LOG RUN

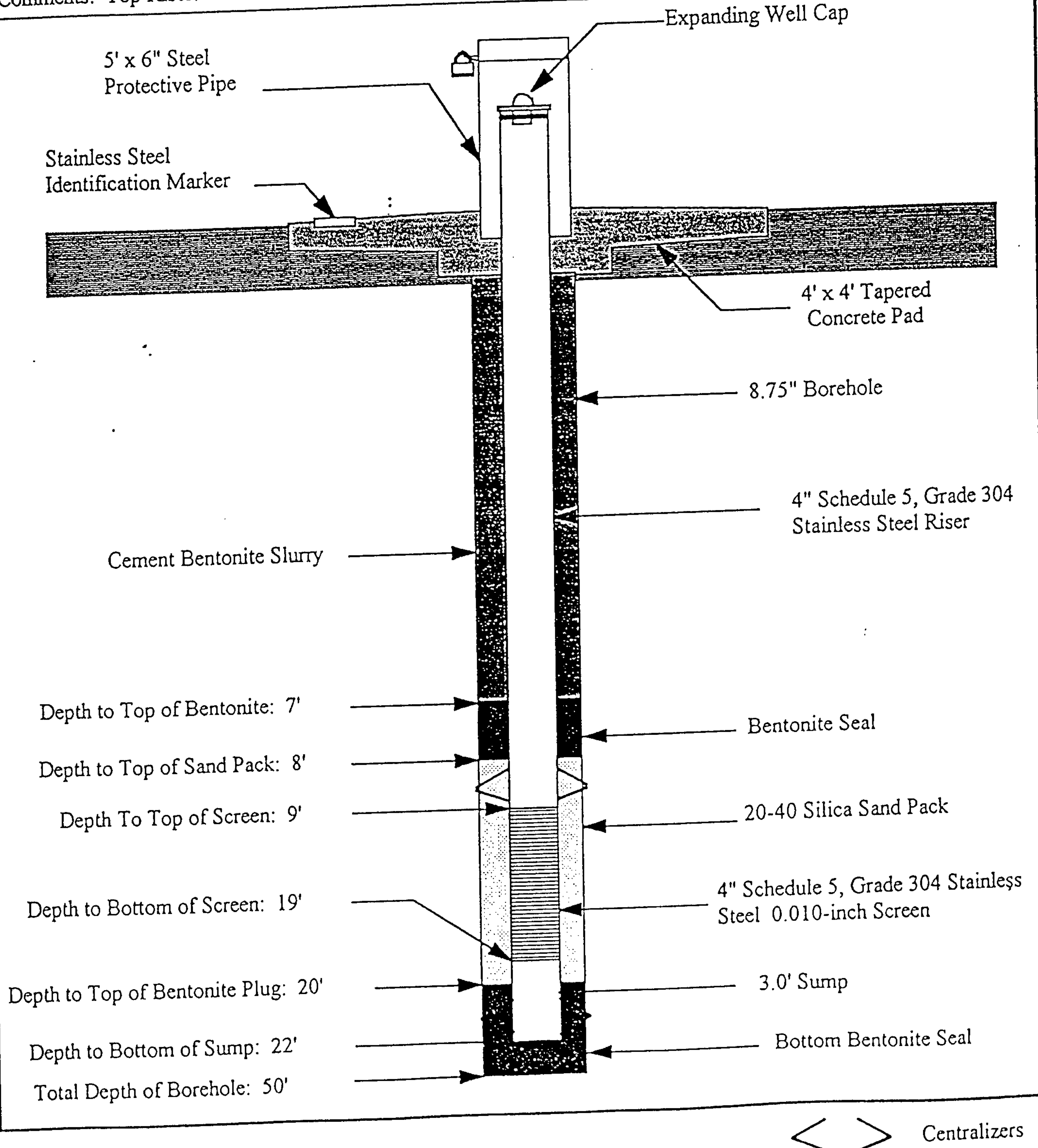
2. LOG RUN

Well Design Delivered 6-13-95

WELL CONSTRUCTION SCHEMATIC

Client: Tinker Air Force Base	Well ID: 2-152B
Location: TAFB, Oklahoma	Site: BW
Contract No: F34650-94-D-0082/5004 (P & A 3)	Date 4-Inch Riser Set: 05/18/95
Contractor: Brown & Root Environmental	Drilling Method: Mud Rotary
Project Manager: David Parker	Ground Level Elev. (AMSL): 1243.46'
Project Geologist: James W. Roberts	Top of Csg. Elev. (AMSL): 1246.06'
Drlg Contractor: Associated Environmental, Inc.	Dedicated Pump: 2-inch Grundfos

Comments: Top Riser: 4" Schedule 40 PVC Casing. 1' thick top seal set. Top of sand set 1' above screen.



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2-2A

Client: TINKER AFB
Project Name: TINKER 5000
Project Location: TINKER AFB, OKLAHOMA
Project Number: 409802

MONITORING WELL 2-

DRILLING AND SAMPLING INFORMATION

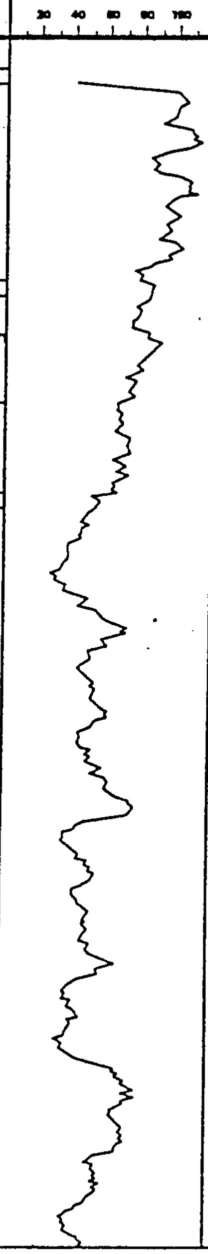
Boring Location: AREA A
PAD ELEV.(FT): 1240.51
TOTAL DEPTH(FT.): 70.5
Logged By: V. CRNICH, P. SCHUMANN
Date Started: 11/9/93
Drilled By: T. PATTERSON, NESCO; A. SORIANO, GPI
Date Completed: 11/24/93
Drill Rig Type: SIMCO, MOBILE B-61
Drilling Method: HOLLOW STEM AUGER AND MUD ROTARY
Sampling Method: CONTINUOUS SAMPLER
Notes: 6" AND 8" BOREHOLE; DESCRIPTIONS BELOW 40' PARTIALLY BASED ON GAMMA LOG
COORDINATES–NAD 27: N 158259.233, E 2180356.152

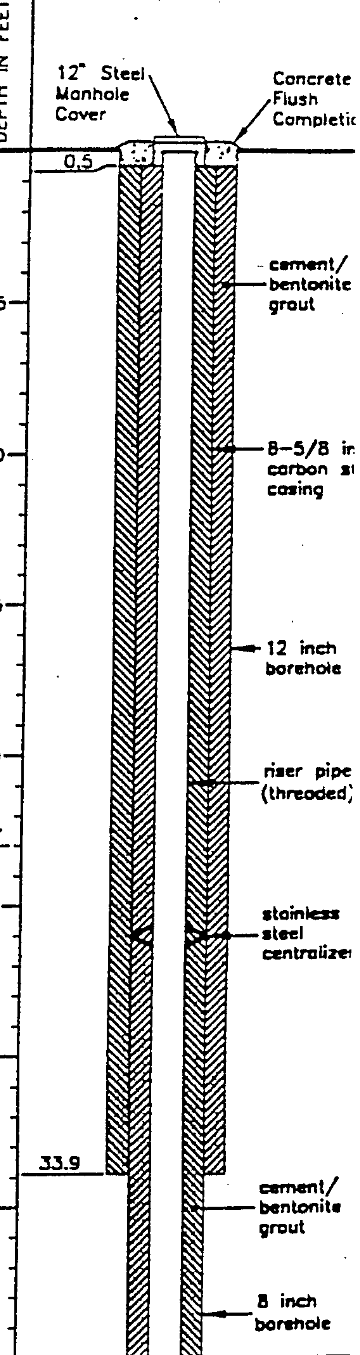
WELL COMPLETION DATA

Elev–Top of Casing(ft.): 1242.96 Ref. Datum: NGVD
1. Surf Casing–I.D.(in.): 8-5/8 Depth(ft.): 33.9 Type: Carbon
Centralizers–Type: Depths(ft.):
2. Riser Pipe–I.D.(in.): 2 Depth(ft.): 60.0 Type: S.Steel
Centralizers–Type: S.Steel Depths(ft.): 26.0, 59.0
3. Screen Dia.(in.): 2 Type: S.Steel Millslotted
Depth Interval(ft.): 60.0–70.0 Slot Size(in.): .010
Centralizers–Type: Depths(ft.):
4. Filter Pack Type: Silica Sand Depth Interval(ft.): 58.0–70.5
Conc. Pad Size: 4'x4'x6"

DESCRIPTION	SAMPLE TYPE	SAMPLE NO.	IN. DRIVEN	IN. RECOVERED	PID	USCS	DEPTH IN FEET
TOPSOIL			60				
CLAYEY SAND – very fine grained sand; loose; moist; red (2.5YR-4/6)	A	1354			14	sc	
SANDY CLAY – slightly plastic; firm; dry; greenish brown (10YR-3/2) – nonplastic; hard; black streaks – slightly plastic; firm; moist; red (2.5YR-4/6)			48	29		cl	5
CLAYEY SAND – very fine grained sand; loose; moist; red (2.5YR-4/6); hydrocarbon odor	A	1355		48	174	sc	
SANDY CLAY – slightly plastic; soft; moist; greenish gray (5Y-7/1); strong hydrocarbon odor – alternating small sand zones with clay lens; red (2.5YR-4/6); hydrocarbon odor at 9' – small zones of hard siltstone at 10.5'	A	1356	36	36	313	cl	10
SILTSTONE – interbedded with clayey sand; small broken zones of hard siltstone; black streaks; weak hydrocarbon odor			12	12	7		
CLAYEY SAND – very fine grained sand; loose; moist; red (2.5YR-4/6)			24	24		sc	15
SILTSTONE / MUDSTONE – interbedded thin zones; crumbly; broken; moist; reddish pink (5YR-7/4) – too hard							20
SAND – very fine grained; loose; wet; red (2.5YR-4/6)						sp	25
SANDY CLAY						cl	30
CLAYEY SAND						sc	35
SAND – very fine to fine grained; well compacted						sp	40

GEOPHYSICAL LOG (GAMMA)





DRAFT BY	RPS 2/9/94	DRAFT CHK		PROJ. CHK		APPRV. BY		DWG. NO.	409802–A29 Sheet 1 of 2

2-2A

Client: TINKER AFB
Project Name: TINKER 5000

Project Location: TINKER AFB, OKLAHOMA
Project Number: 409802

MONITORING WELL 2-

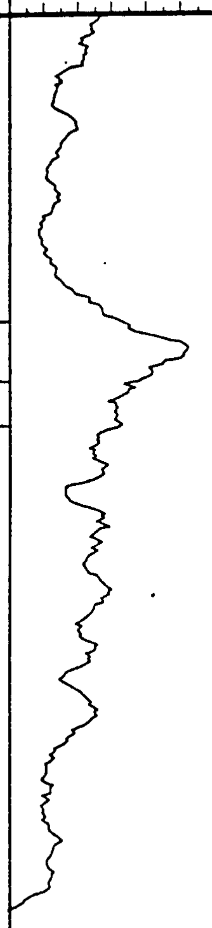
DRILLING AND SAMPLING INFORMATION

Boring Location: AREA A
PAD ELEV.(FT): 1240.51
TOTAL DEPTH(FT.): 70.5
Logged By: V. CRNICH, P. SCHUMANN
Date Started: 11/9/93
Drilled By: T. PATTERSON, NESCO
A. SORIANO, GPI
Date Completed: 11/24/93
Drill Rig Type: SIMCO, MOBILE B-61
Drilling Method: HOLLOW STEM AUGER AND MUD ROTARY
Sampling Method: CONTINUOUS SAMPLER
Notes: 6" AND 8" BOREHOLE; DESCRIPTIONS BELOW 40' PARTIALLY BASED ON GAMMA LOG
COORDINATES—NAD 27: N 158259.233, E 2180356.152

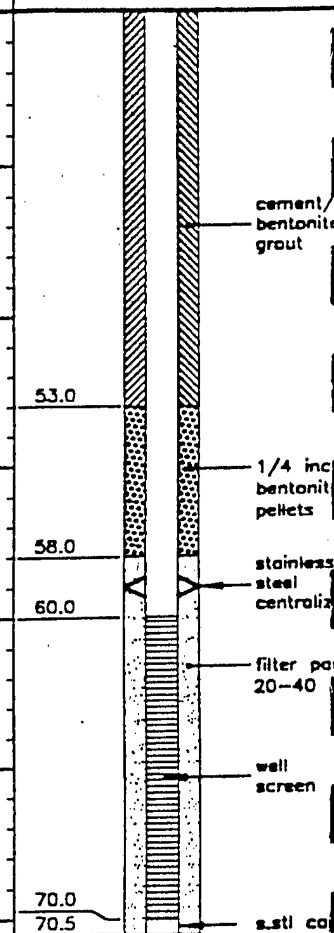
WELL COMPLETION DATA

Elev—Top of Casing(ft.): 1242.96 Ref. Datum: NGVD
1. Surf Casing—I.D.(in.): 8-5/8 Depth(ft.): 33.9 Type: Carbon
Centralizers—Type: Depths(ft.):
2. Riser Pipe—I.D.(in.): 2 Depth(ft.): 60.0 Type: S.Steel
Centralizers—Type: S.Steel Depths(ft.): 26.0, 59.0
3. Screen Dia.(in.): 2 Type: S.Steel Millslotted
Depth Interval(ft.): 60.0—70.0 Slot Size(in.): .010
Centralizers—Type: Depths(ft.):
4. Filter Pack Type: Silica Sand Depth Interval(ft.): 58.0—70.5
Conc. Pad Size: 4'x4'x6"

DESCRIPTION	GEOPHYSICAL LOG (GAMMA) 20 40 60 80 100	SAMPLE TYPE	SAMPLE NO.	IN. DRIVEN	IN. RECOVERED	PID	USCS	GRAPHIC LOG	DEPTH IN FEET
CLAY							ch		
CLAYEY SILT							ml		
SAND — very fine to fine grained; well compacted							sp		
TOTAL DEPTH = 70.5 FEET									



Depth in feet: 45, 50, 55, 60, 65, 70, 75, 80



DRAFT BY	RPS 2/9/94	DRAFT CHK		PROJ. CHK		APPRV. BY		DWG. NO.	409802—A2 Sheet 2 of 2

2-4A

Client: TINKER AFB
Project Name: TINKER 5000
Project Location: TINKER AFB, OKLAHOMA
Project Number: 409802

MONITORING WELL 2-

DRILLING AND SAMPLING INFORMATION

Boring Location: AREA A
PAD ELEV.(FT): 1240.98
TOTAL DEPTH(FT.): 74.0
Logged By: P. SCHUMANN, V. CRNICH
Date Started: 11/22/93
Drilled By: J. WALKER GPI
Date Completed: 12/29/93
Drill Rig Type: MOBILE B-61 AND TH-60
Drilling Method: HOLLOW STEM AUGER AND MUD ROTARY
Sampling Method: 3" I.D CONTINUOUS SAMPLER

Notes: 8" BOREHOLE
COORDINATES-NAD 27: N 158368.779, E 2180374.657

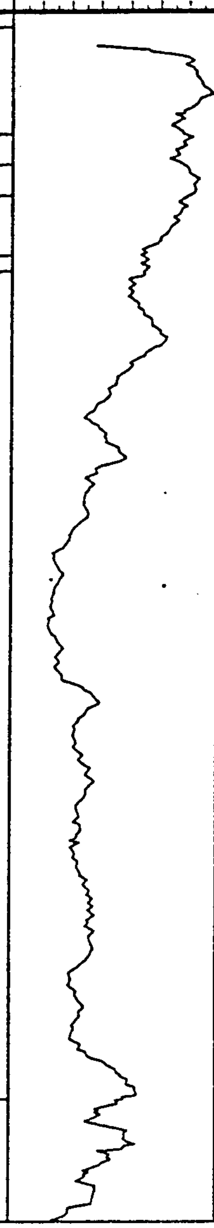
WELL COMPLETION DATA

Elev-Top of Casing(ft.): 1240.81 Ref. Datum: NGVD

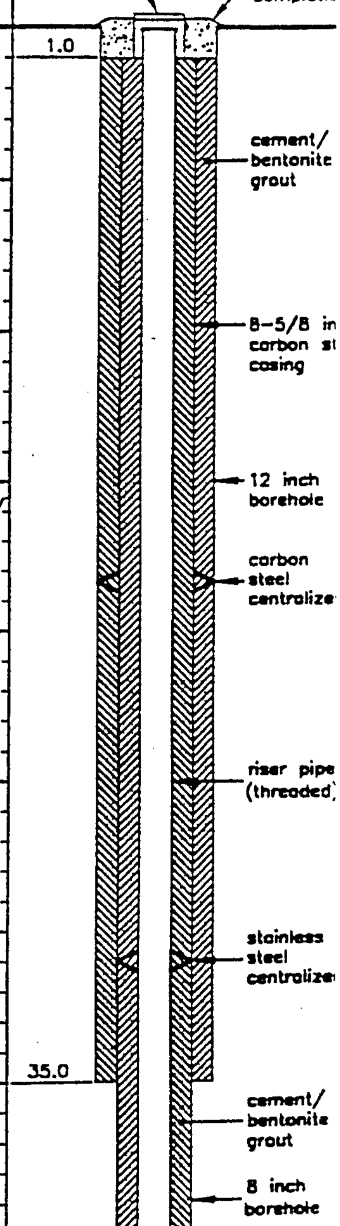
1. Surf Casing-I.D.(in.): 8-5/8 Depth(ft.): 35.0 Type: Carbon :
   Centralizers-Type: C.Steel Depths(ft.): 18.4
2. Riser Pipe-I.D.(in.): 2 Depth(ft.): 61.0 Type: S.Steel
   Centralizers-Type: S.Steel Depths(ft.): 31.0
3. Screen Dia.(in.): 2 Type: S.Steel Millslotted
   Depth Interval(ft.): 61.0-71.0 Slot Size(in.): .010
   Centralizers-Type: S.Steel Depths(ft.): 60.4
4. Filter Pack Type: Silica Sand Depth Interval(ft.): 59.0-71.5
   Conc. Pad Size: 4'x4'x6"

DESCRIPTION	SAMPLE TYPE / SAMPLE NO.	IN. DRIVEN / IN. RECOVERED	PID	USCS
GRAVEL		48	0	
SILTY CLAY – highly plastic; 5% silt; soft; moist; reddish black (2.5YR-2.5/1)	A 1357	40	0, 0	ch
CLAY – highly plastic; soft; moist; reddish black (2.5YR-2.5/1); strong odor	A 1358	24 / 24	74, 14	ch
SILTY CLAY – slightly plastic; 20% silt; hard; moist; red (2.5YR-6/8)	J 5429	36	25	cl
CLAY – highly plastic; hard; moist; dark red (2.5YR-4/6); odor		36	63, 174	ch
SILTY CLAY – nonplastic; 30% silt; soft; moist; light blueish gray (5B-7/1); strong odor	A 1359	12 / 12	227, 94	cl
CLAYEY SILT – 5% clay; poorly graded; loose; moist; red (2.5YR-6/8); strong odor – firm – wet	A 1360	48 / 10; 24 / 24; 48 / 0; 60 / 0; 24 / 24	143, 172, 359, 250, 300, 210	ml
SILTY CLAY – nonplastic; 5% silt; hard; moist; red (2.5YR-6/8)		24 / 24		cl

GEOPHYSICAL LOG (GAMMA)



GRAPHIC LOG — DEPTH IN FEET 5, 10, 15, 20, 25, 30, 35, 40



DRAFT BY	RPS 2/9/94	DRAFT CHK		PROJ. CHK		APPRV. BY		DWG. NO.	409802-A30 Sheet 1 of 2

2-4A

Client: TINKER AFB
Project Name: TINKER 5000

Project Location: TINKER AFB, OKLAHOMA
Project Number: 409802

MONITORING WELL 2-

DRILLING AND SAMPLING INFORMATION

Boring Location: AREA A

PAD ELEV.(FT): 1240.98
TOTAL DEPTH(FT.): 74.0

Logged By: P. SCHUMANN, V. CRNICH
Drilled By: J. WALKER
GPI

Date Started: 11/22/93
Date Completed: 12/29/93

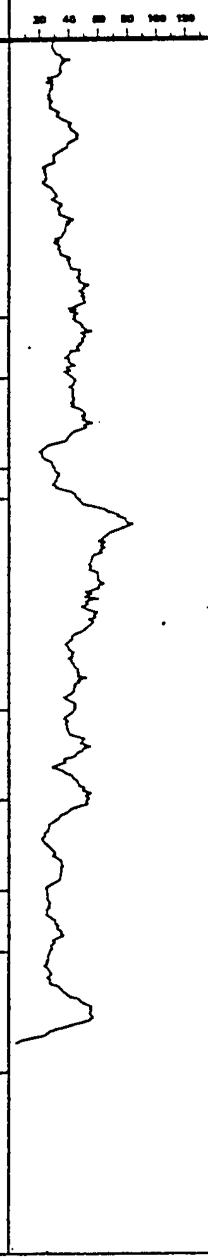
Drill Rig Type: MOBILE B-61 AND TH-60
Drilling Method: HOLLOW STEM AUGER AND MUD ROTARY
Sampling Method: 3" I.D CONTINUOUS SAMPLER

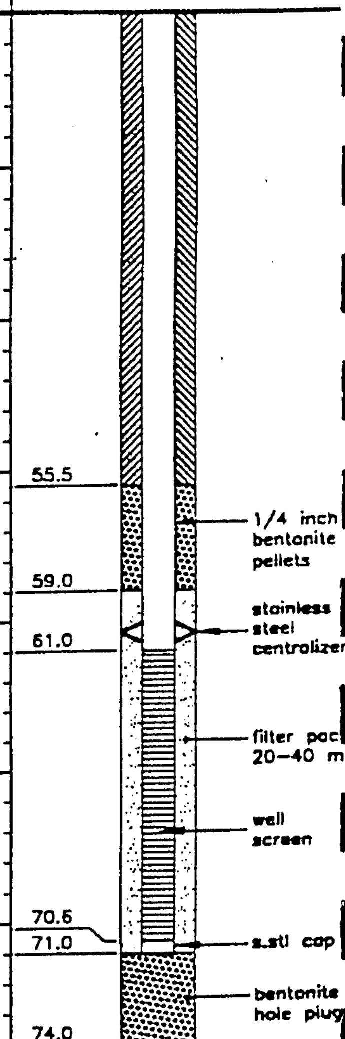
Notes: 8" BOREHOLE
COORDINATES-NAD 27: N 158368.779, E 2180374.657

WELL COMPLETION DATA

Elev-Top of Casing(ft.): 1240.81 Ref. Datum: NGVD
1. Surf Casing-I.D.(in.): 8-5/8 Depth(ft.): 35.0 Type: Carbon
   Centralizers-Type: C.Steel Depths(ft.): 18.4
2. Riser Pipe-I.D.(in.): 2 Depth(ft.): 61.0 Type: S.Steel
   Centralizers-Type: S.Steel Depths(ft.): 31.0
3. Screen Dia.(in.): 2 Type: S.Steel Millslotted
   Depth Interval(ft.): 61.0-71.0 Slot Size(in.): .010
   Centralizers-Type: S.Steel Depths(ft.): 60.4
4. Filter Pack Type: Silica Sand Depth Interval(ft.): 59.0-71.5
   Conc. Pad Size: 4'x4'x6"

DESCRIPTION	GEOPHYSICAL LOG (GAMMA)	SAMPLE TYPE / SAMPLE NO.	IN. DRIVEN / IN. RECOVERED	PID	USCS	GRAPHIC LOG	DEPTH IN FEET
- slightly silty							
- slightly plastic							45
SILTY SAND - slightly silty; compact; red (2.5YR-6/8)					sm		50
SILTY CLAY - slightly plastic; slightly silty; soft; red (2.5YR-6/8)					cl		
CLAYEY SAND - medium grained sand; red to dark red (2.5YR-6/8)					sp		55
SANDY CLAY - slightly plastic; medium grained sand; firm; red (2.5YR-6/8)					cl		60
SILTY SAND - red (2.5YR-6/8)					sm		
CLAYEY SAND - fine grained sand; red (2.5YR-6/8)					sc		65
SAND					sp		70
SANDY CLAY AND CLAYEY SAND					sc-ch		
TOTAL DEPTH = 74.0 FEET							75
							80





DRAFT BY	RPS 2/9/94	DRAFT CHK		PROJ. CHK		APPRV. BY		DWG. NO.	409802-A30 Sheet 2 of 2

Client: TINKER AFB
Project Name: TINKER 5000
Project Location: TINKER AFB, OKLAHOMA
Project Number: 409802

MONITORING WELL 2-51

DRILLING AND SAMPLING INFORMATION

Boring Location: SOUTHEAST OF BUILDING 410
Logged By: V. CRNICH
Drilled By: J. WALKER GPI
Drill Rig Type: TH-60, INGERSOL RAND
Drilling Method: HOLLOW STEM AUGER AND MUD ROTARY
Sampling Method: 2'x2" CONTINUOUS SPLIT SPOON

PAD ELEV.(FT): 1241.77
TOTAL DEPTH(FT.): 74.0
Date Started: 11/8/93
Date Completed: 12/27/93

Notes: 8" AND 12" BOREHOLE
COORDINATES-NAD 27: N 158317.014, E 2180427.678

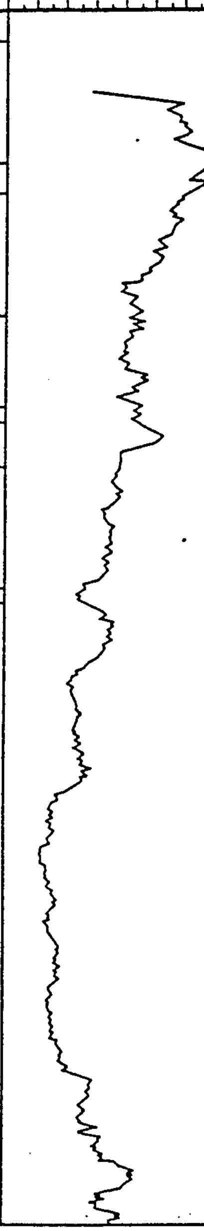
WELL COMPLETION DATA

Elev-Top of Casing(ft.): 2141.65 — Ref. Datum: NGVD

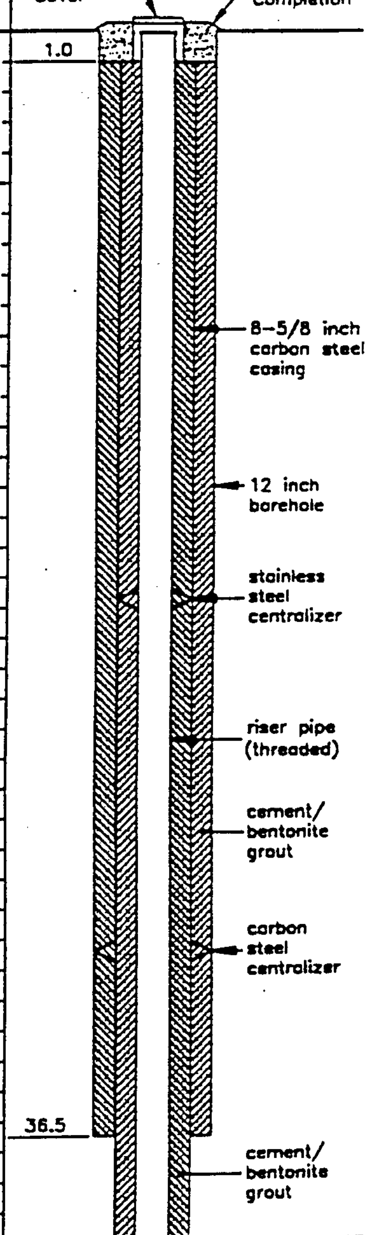
1. Surf Casing-I.D.(in.): 8-5/8 — Depth(ft.): 36.5 — Type: Carbon Ste
   Centralizers-Type: C.Steel — Depths(ft.): 18.75
2. Riser Pipe-I.D.(in.): 2 — Depth(ft.): 61.6 — Type: S.Steel
   Centralizers-Type: S.Steel — Depths(ft.): 30.4, 61.0
3. Screen Dia.(in.): 2 — Type: S.Steel Millslotted
   Depth Interval(ft.): 61.6-71.6 — Slot Size(in.): .010
   Centralizers-Type: — Depths(ft.):
4. Filter Pack Type: Silica Sand — Depth Interval(ft.): 60.1-74.0
   Conc. Pad Size: 4'x4'x6"

DESCRIPTION	SAMPLE TYPE / SAMPLE NO.	IN. DRIVEN / IN. RECOVERED	PID	USCS
TOPSOIL - grass; (10YR-4/4)				
SANDY CLAY - slightly plastic; soft; moist; red (2.5YR-4/6); black inclusions; no odor	A 1350	60 / 20	1	cl
CLAY - slightly plastic; firm; moist; dark brown (7.5Y-4/2); black inclusions	A 1351	60 / 36	17	cl
SANDY CLAY - slightly plastic; firm to stiff; moist; red (2.5YR-4/6); black inclusions and streaks; weak hydrocarbon odor - soft; greenish gray (5Y-7/1) (at 7')				cl
CLAYEY SAND - 65% sand; loose; dry; red (2.5YR-4/6); weak hydrocarbon odor - stronger hydrocarbon odor	A 1352	60 / 41	20	sc
SANDY CLAY - slightly plastic; firm; moist; red (2.5YR-4/6); hydrocarbon odor				cl
SILTY SAND - very fine grained sand; loose; moist; red (2.5YR-4/6); hydrocarbon odor			4	sm
CLAYEY SAND - fine grained sand; loose; moist; red (2.5YR-4/6); no odor - zones of compact sand		24 / 24		sc
SAND - fine grained; firm; dry; dark red to pink	A 1353	36 / 36		sp
SANDSTONE - fine grained; broken; dry; dark red (2.5YR-4/6) - auger refusal; stopped sampling		12 / 6		sp
SILTY CLAY - slightly plastic; 40% silt; red (2.5YR-4/6)				cl

GEOPHYSICAL LOG (GAMMA)



GRAPHIC LOG — DEPTH IN FEET: 5, 10, 15, 20, 25, 30, 35, 40



DRAFT BY	RPS 8/19/94	DRAFT CHK		PROJ. CHK		APPRV. BY		DWG. NO.	409802-A76 Sheet 1 of 2

Client: TINKER AFB
Project Name: TINKER 5000
Project Location: TINKER AFB, OKLAHOMA
Project Number: 409802

MONITORING WELL 2-51

DRILLING AND SAMPLING INFORMATION

Boring Location: SOUTHEAST OF BUILDING 410
Logged By: V. CRNICH
Drilled By: J. WALKER GPI
Drill Rig Type: TH-60, INGERSOL RAND
Drilling Method: HOLLOW STEM AUGER AND MUD ROTARY
Sampling Method: 2'x2" CONTINUOUS SPLIT SPOON

PAD ELEV.(FT): 1241.77
TOTAL DEPTH(FT.): 74.0
Date Started: 11/8/93
Date Completed: 12/27/93

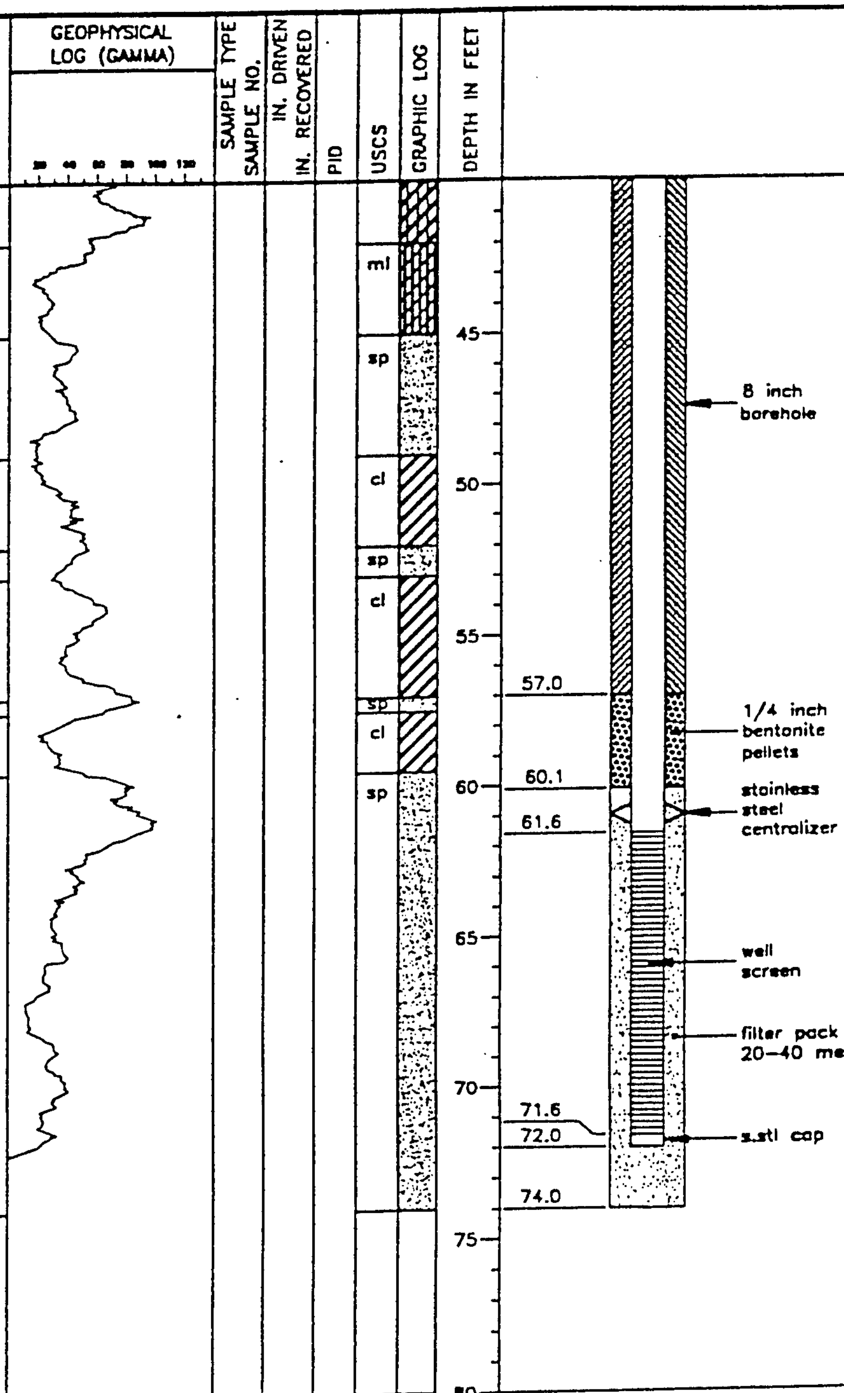
Notes: 8" AND 12" BOREHOLE
COORDINATES-NAD 27: N 158317.014, E 2180427.678

WELL COMPLETION DATA

Elev-Top of Casing(ft.): 2141.65 Ref. Datum: NGVD

1. Surf Casing-I.D.(in.): 8-5/8 Depth(ft.): 36.5 Type: Carbon St
   Centralizers-Type: C.Steel Depths(ft.): 18.75
2. Riser Pipe-I.D.(in.): 2 Depth(ft.): 61.6 Type: S.Steel
   Centralizers-Type: S.Steel Depths(ft.): 30.4, 61.0
3. Screen Dia.(in.): 2 Type: S.Steel Millslotted
   Depth Interval(ft.): 61.6-71.6 Slot Size(in.): .010
   Centralizers-Type: Depths(ft.):
4. Filter Pack Type: Silica Sand Depth Interval(ft.): 60.1-74.0
   Conc. Pad Size: 4'x4'x6"

DESCRIPTION
CLAYEY SILT - red (2.5YR-4/6)
SAND - firm; red (2.5YR-4/6); well consolidated; drilled slower
CLAY - slightly plastic; slightly silty; red (2.5YR-4/6)
SAND - firm; red (2.5YR-4/6); well consolidated
CLAY - slightly silty; red (2.5YR-4/6)
SAND - firm; red (2.5YR-4/6); drilled slower
CLAY - slightly plastic; red (2.5YR-4/6)
SAND - firm; red (2.5YR-4/6)
TOTAL DEPTH = 74.0 FEET



DRAFT BY	RPS 8/19/94	DRAFT CHK		PROJ. CHK		APPRV. BY		DWG. NO.	409802-A76 Sheet 2 of 2

2-52A

Client: TINKER AFB
Project Name: TINKER 5000
Project Location: TINKER AFB, OKLAHOMA
Project Number: 409802

MONITORING WELL 2-5

DRILLING AND SAMPLING INFORMATION

Boring Location: AREA A
PAD ELEV.(FT): 1239.83
TOTAL DEPTH(FT.): 72.0
Logged By: V. CRNICH
Date Started: 11/3/93
Drilled By: T. PATTERSON, D. FORSTER NESCO
Date Completed: 11/10/93
Drill Rig Type: SIMCO, FAILING 1250
Drilling Method: HOLLOW STEM AUGER AND MUD ROTARY
Sampling Method: 5'x2.5" CONTINUOUS SAMPLER

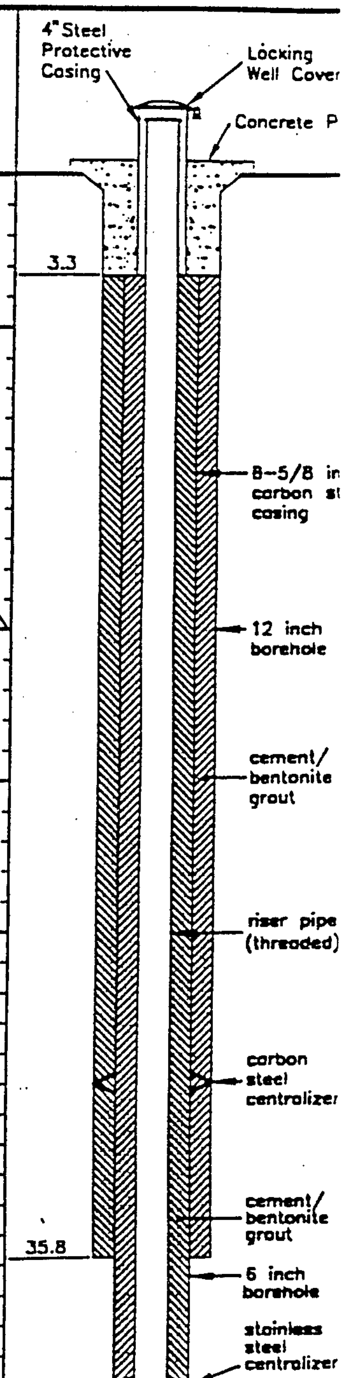
Notes: 6-1/4" BOREHOLE AND 12" BOREHOLE
COORDINATES-NAD 27: N 158283.581, E 2180247.928

WELL COMPLETION DATA

Elev-Top of Casing(ft.): 1241.98 **Ref. Datum:** NGVD
1. **Surf Casing-I.D.(in.):** 8-5/8 **Depth(ft.):** 35.8 **Type:** Carbon
   Centralizers-Type: S.Steel **Depths(ft.):** 30.0
2. **Riser Pipe-I.D.(in.):** 2 **Depth(ft.):** 56.8 **Type:** S.Steel
   Centralizers-Type: S.Steel **Depths(ft.):** 40.0
3. **Screen Dia.(in.):** 2 **Type:** S.Steel Millslotted
   Depth Interval(ft.): 56.8-66.5 **Slot Size(in.):** .010
   Centralizers-Type: S.Steel **Depths(ft.):** 60.4
4. **Filter Pack Type:** Silica Sand **Depth Interval(ft.):** 55.0-66.8
   Conc. Pad Size: 4'x4'x6"

DESCRIPTION	SAMPLE TYPE	SAMPLE NO.	IN. DRIVEN / IN. RECOVERED	PID	USCS	DEPTH IN FEET
TOPSOIL			60	1.2		
SANDY CLAY - slightly plastic; fine grained sand; stiff; moist; dark brown (2.5YR-4/2); black pebbles	A	1347			cl	
- firm			24 / 60			5
- hard; red (2.5YR-4/6); black streaks	A	1348		74		
	A	1349	48 / 60	317		10
CLAYEY SAND - very fine to fine grained sand; loose; moist; red (2.5YR-4/6); hydrocarbon odor - dry; weak hydrocarbon odor					sc	
SILTY CLAY - slightly plastic; stiff; moist; red (2.5YR-4/6)			42		cl	15
SAND - very fine to fine grained; loose; wet; red (2.5YR-4/6)			24 / 24		sp	
SILTY SAND - 80% fine grained sand; loose; wet; red (2.5YR-4/6)			36 / 24		sm	20
SAND - fine grained; loose; wet; red (2.5YR-4/6) - slightly silty			36 / 24		sp	
SANDY CLAY - slightly plastic; firm; moist; red (2.5YR-4/6); chunks of fine grained sandstone in matrix			12 / 12		cl	
SAND - fine grained; loose; wet; red (2.5YR-4/6)					sp	25
- fine to medium grained; firm; moist; occassional broken zones			120			30
						35
			60			40

GEOPHYSICAL LOG (GAMMA)



DRAFT BY	RPS 3/2/94	DRAFT CHK		PROJ. CHK		APPRV. BY		DWG. NO.	409802-A38 Sheet 1 of 2

2-52A

Client: TINKER AFB
Project Name: TINKER 5000
Project Location: TINKER AFB, OKLAHOMA
Project Number: 409802

MONITORING WELL 2-5[illegible]

DRILLING AND SAMPLING INFORMATION

Boring Location: AREA A
PAD ELEV.(FT): 1239.83
TOTAL DEPTH(FT.): 72.0
Logged By: V. CRNICH
Date Started: 11/3/93
Drilled By: T. PATTERSON, D. FORSTER NESCO
Date Completed: 11/10/93
Drill Rig Type: SIMCO, FAILING 1250
Drilling Method: HOLLOW STEM AUGER AND MUD ROTARY
Sampling Method: 5'x2.5" CONTINUOUS SAMPLER

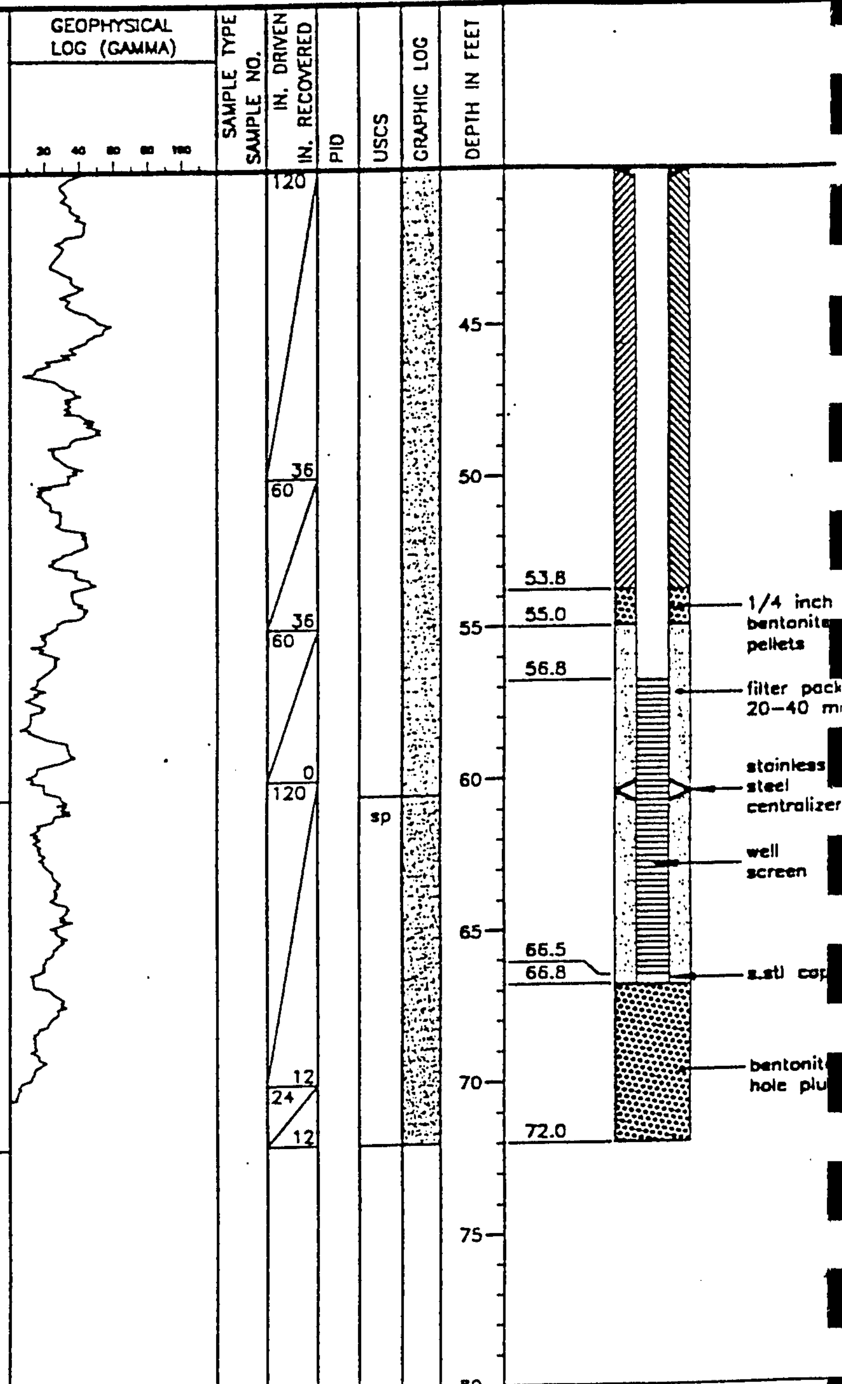
Notes: 6-1/4" BOREHOLE AND 12" BOREHOLE
COORDINATES-NAD 27: N 158283.581, E 2180247.928

WELL COMPLETION DATA

Elev-Top of Casing(ft.): 1241.98 **Ref: Datum:** NGVD

1. **Surf Casing-I.D.(in.):** 8-5/8 **Depth(ft.):** 35.8 **Type:** Carbon [illegible]
   Centralizers-Type: S.Steel **Depths(ft.):** 30.0
2. **Riser Pipe-I.D.(in.):** 2 **Depth(ft.):** 56.8 **Type:** S.Steel
   Centralizers-Type: S.Steel **Depths(ft.):** 40.0
3. **Screen Dia.(in.):** 2 **Type:** S.Steel Millslotted
   Depth Interval(ft.): 56.8-66.5 **Slot Size(in.):** .010
   Centralizers-Type: S.Steel **Depths(ft.):** 60.4
4. **Filter Pack Type:** Silica Sand **Depth Interval(ft.):** 55.0-66.8
   Conc. Pad Size: 4'x4'x6"

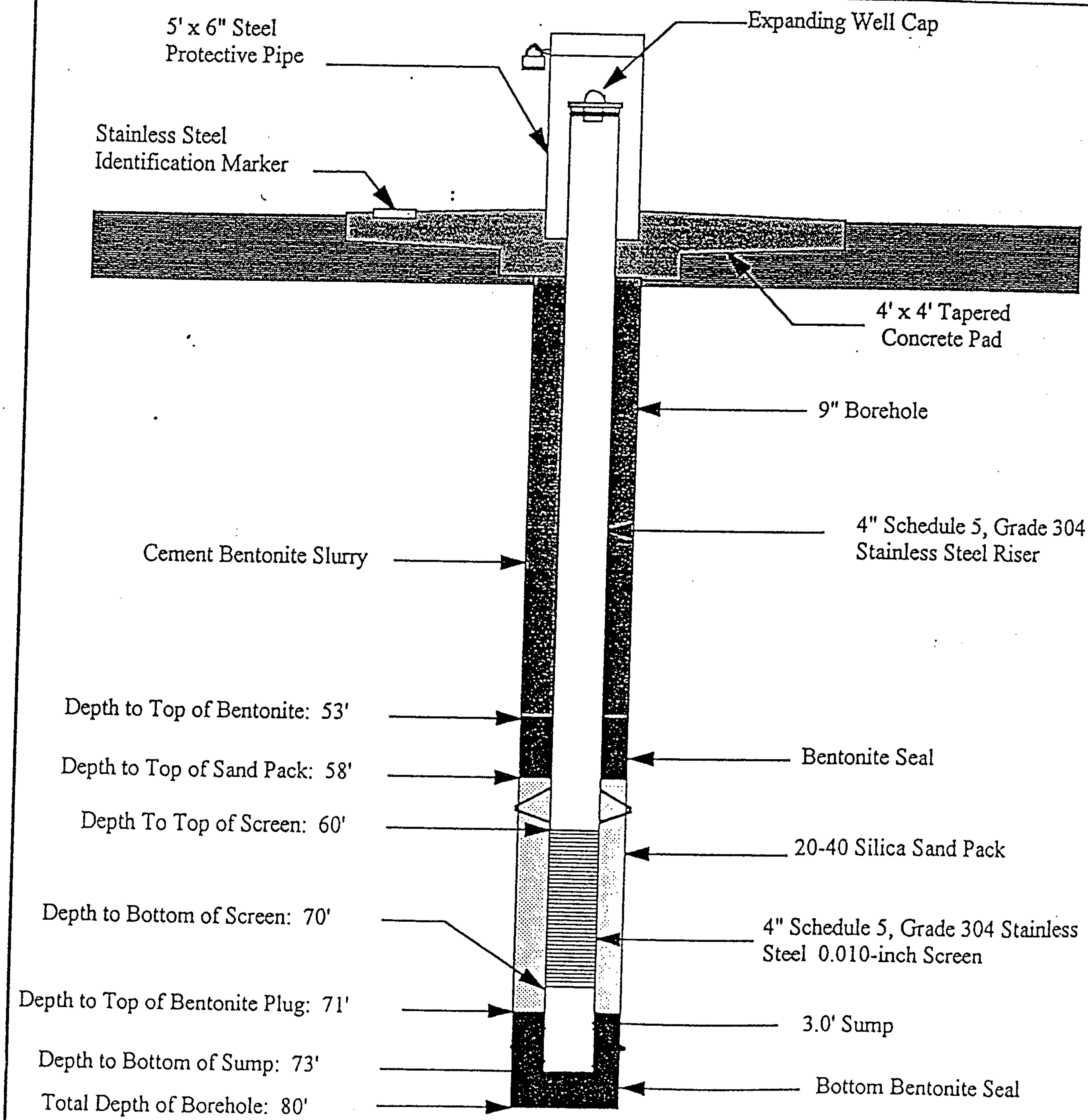
DESCRIPTION
- fine grained; broken gravelly zones
- no recovery (55'-60')
- loose; wet
SANDSTONE - fine grained; compact; dry; red (2.5YR-4/6)
TOTAL DEPTH = 72.0 FEET



DRAFT BY	RPS 3/2/94	DRAFT CHK		PROJ. CHK		APPRV. BY		DWG. NO.	409802-A38 Sheet 2 of 2

WELL CONSTRUCTION SCHEMATIC

Client: Tinker Air Force Base	Well ID: 2-147A
Location: TAFB, Oklahoma	Site: PRM
Contract No: F34650-94-D-0082/5004 (P & A 3)	Date 4-Inch Riser Set: 02/01/95
Contractor: Brown & Root Environmental	Drilling Method: Auger
Project Manager: David Parker	Ground Level Elev. (AMSL): 1268.58'
Project Geologist: James W. Roberts	Top of Csg. Elev. (AMSL): 1271.51'
Drlg Contractor: Associated Environmental, Inc.	Dedicated Pump: 2-inch Grundfos
Comments: Top Riser: 4" Schedule 40 PVC Riser Casing.	

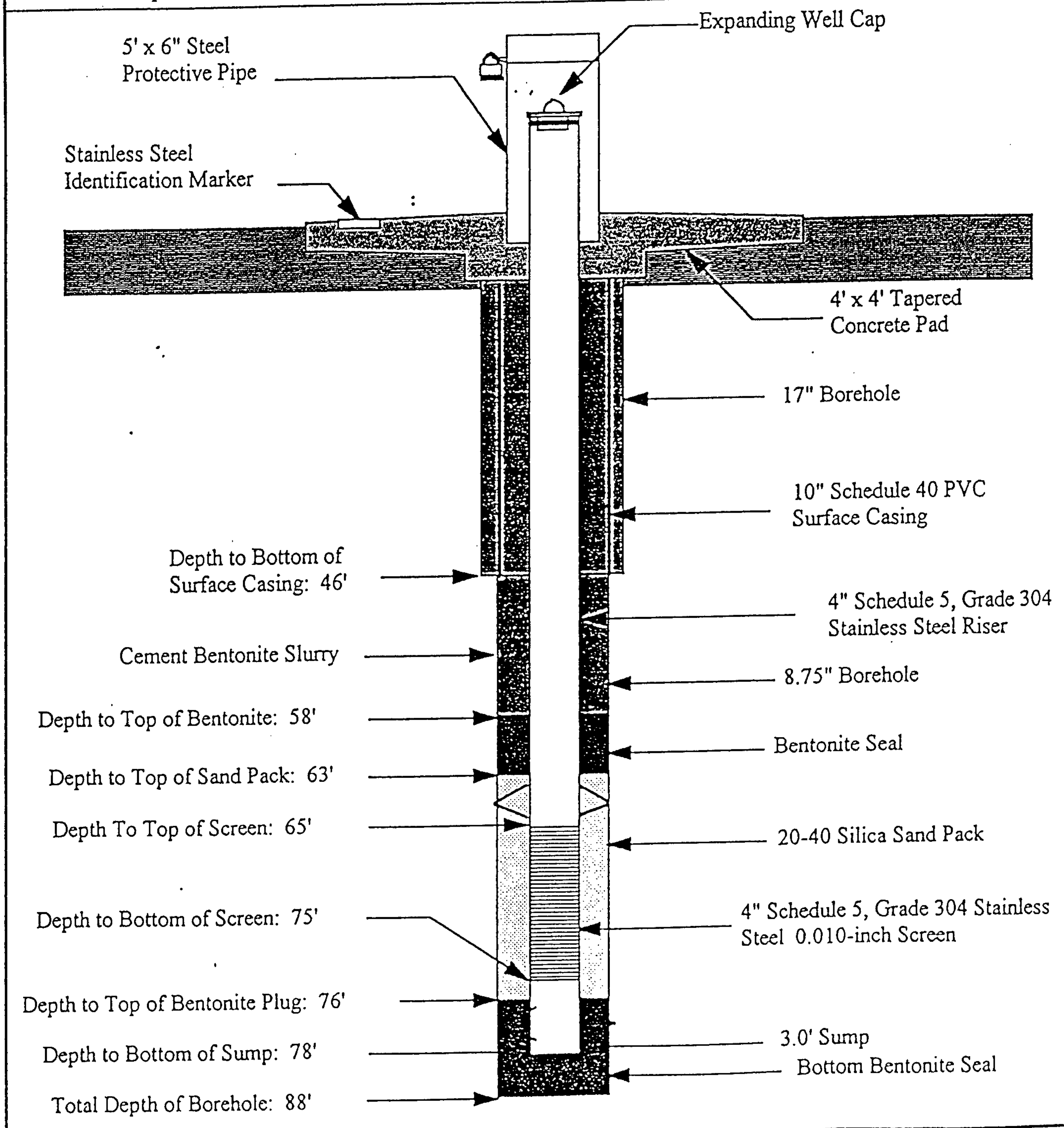


Drawing not to scale

< > Centralizers

WELL CONSTRUCTION SCHEMATIC

Client: Tinker Air Force Base	Well ID: 2-148A
Location: TAFB, Oklahoma	Site: PRM
Contract No: F34650-94-D-0082/5004 (P & A 3)	Date 4-Inch Riser Set: 05/11/95
Contractor: Brown & Root Environmental	Drilling Method: Auger, 0'-46'; Mud Rotary, 46'-88'
Project Manager: David Parker	Ground Level Elev. (AMSL): 1247.45'
Project Geologist: James W. Roberts	Top of Csg. Elev. (AMSL): 1250.11'
Drlg Contractor: Associated Environmental Inc.	Dedicated Pump: 2-inch Grundfos
Comments: Top Riser: 4" Schedule 40 PVC Casing.	

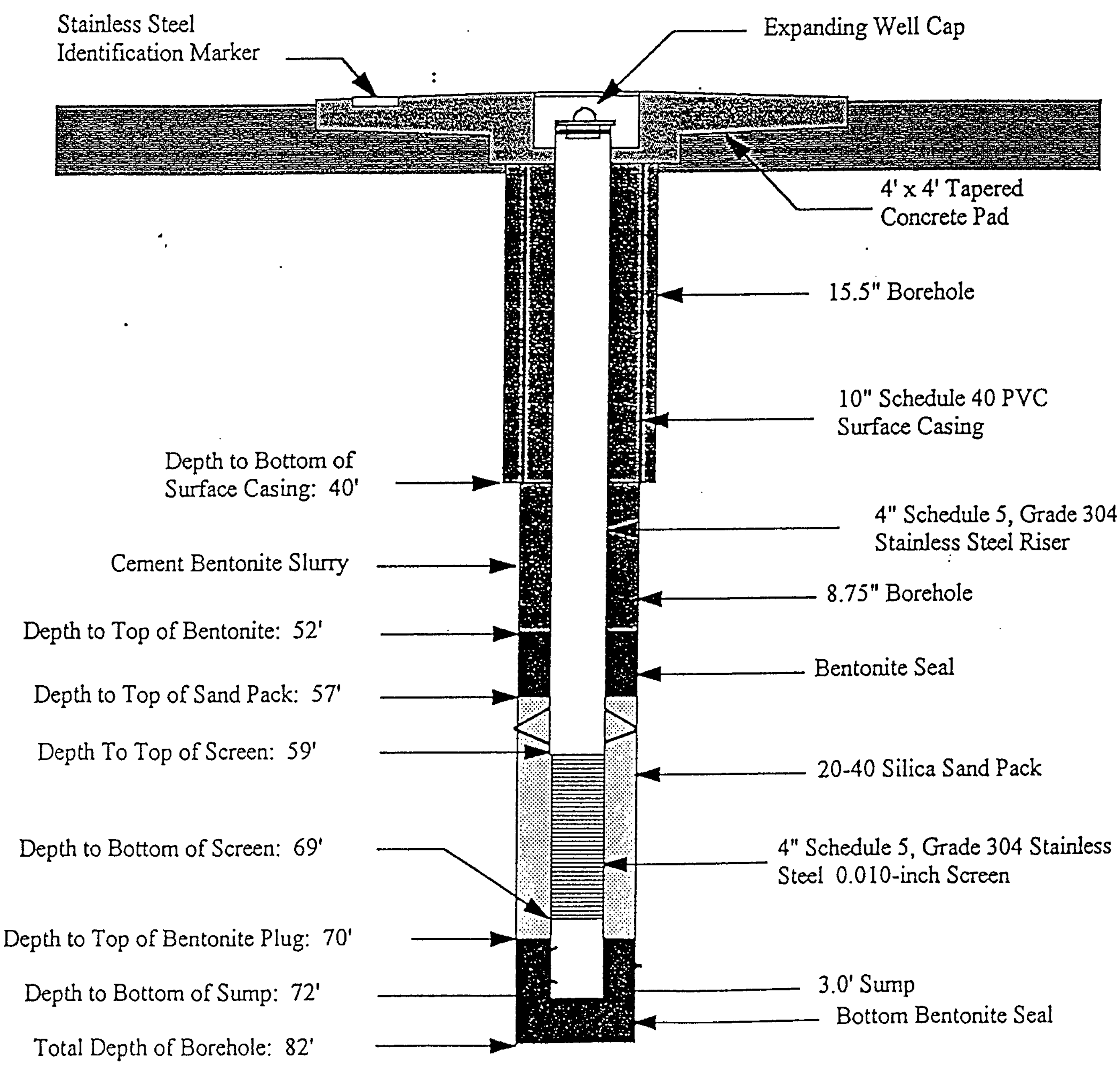


< > Centralizers

Drawing not to scale

WELL CONSTRUCTION SCHEMATIC

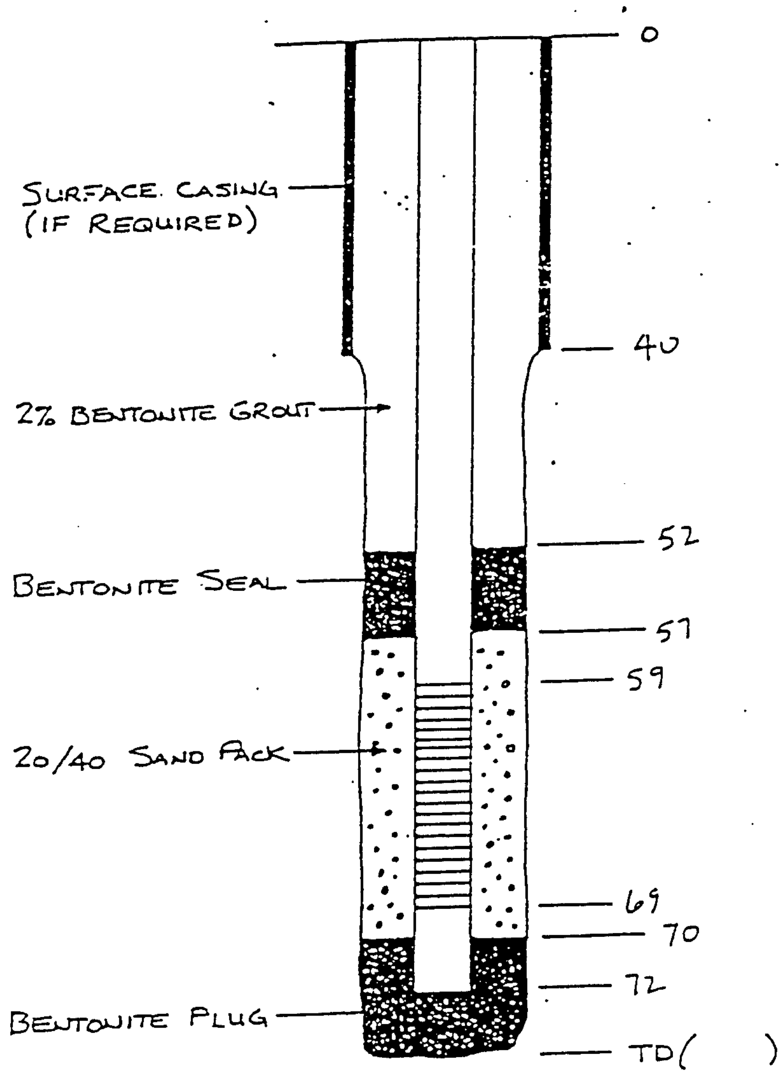
Client: Tinker Air Force Base	Well ID: 2-149A
Location: TAFB, Oklahoma	Site: PRM
Contract No: F34650-94-D-0082/5004 (P & A 3)	Date 4-Inch Riser Set: 06/05/95
Contractor: Brown & Root Environmental	Drilling Method: Mud Rotary
Project Manager: David Parker	Ground Level Elev. (AMSL): 1237.39'
Project Geologist: James W. Roberts	Top of Csg. Elev. (AMSL): 1236.72'
Drlg Contractor: Associated Environmental Inc.	Dedicated Pump: 2-inch Grundfos
Comments: Top Riser: 4" Schedule 40 PVC Casing.	



Drawing not to scale

< > Centralizers

Well ID	Recommended Construction Item	Depth	Comments
2-149A	Surface Casing	0-40	
	Inner Casing	–	
	Grout	0-52	
	Bentonite Seal (top)	52-57	
	Sand Pack	57-70	
	Bentonite Seal (bottom)	70-TD	
	Riser	0-59	
	Screen	59-69	
	Sump	69-72	



Log Received
6-5-95 12:10

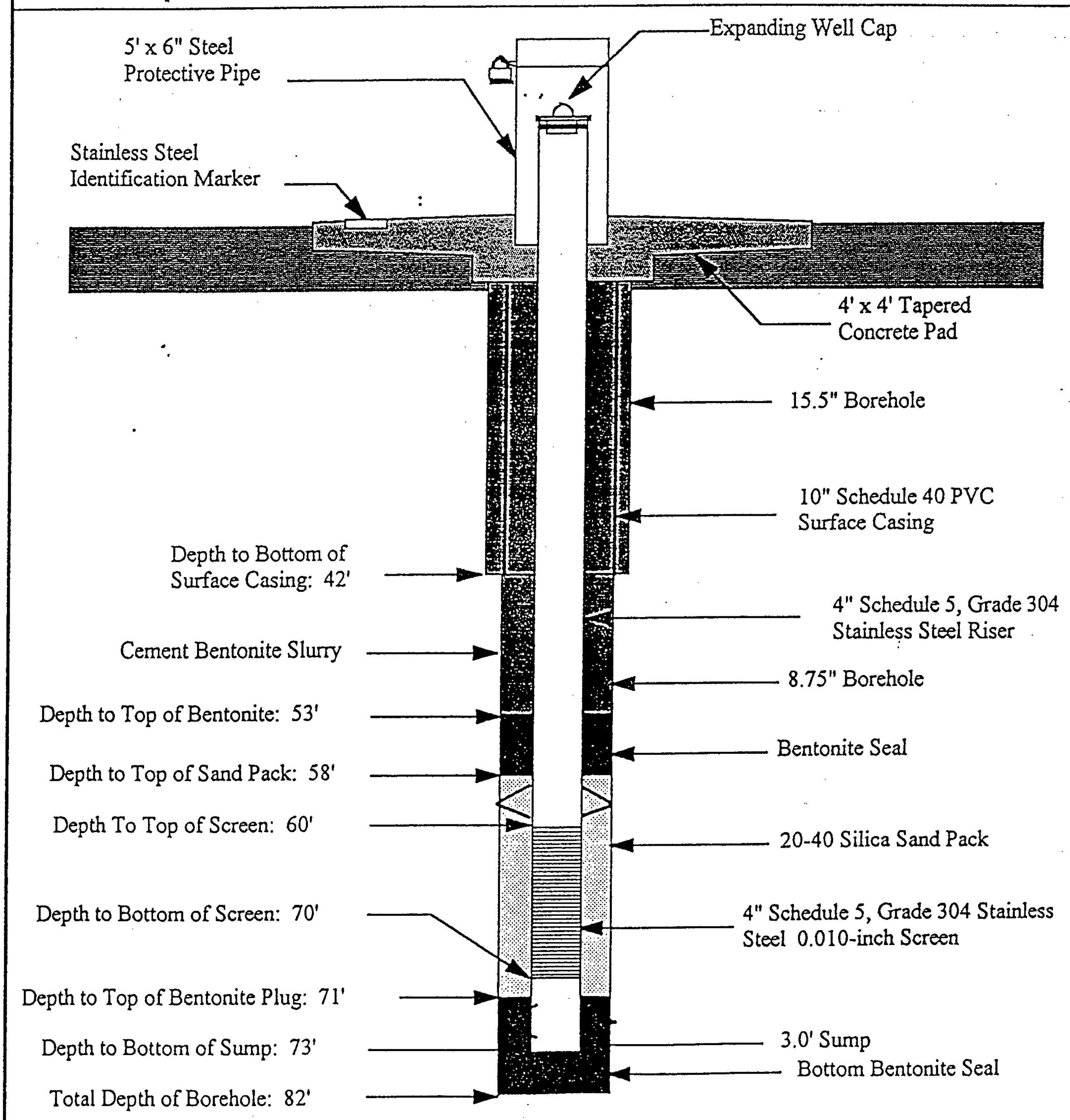
Well Design Delivere
6-5-95 12:10

1 LOG RUN

2 LOG RUN

WELL CONSTRUCTION SCHEMATIC

Client: Tinker Air Force Base	Well ID: **2-150A**
Location: TAFB, Oklahoma	Site: PRM
Contract No: F34650-94-D-0082/5004 (P & A 3)	Date 4-Inch Riser Set: 05/17/95
Contractor: Brown & Root Environmental	Drilling Method: Mud Rotary
Project Manager: David Parker	Ground Level Elev. (AMSL): 1231.28'
Project Geologist: James W. Roberts	Top of Csg. Elev. (AMSL): 1233.80'
Drlg Contractor: Associated Environmental Inc.	Dedicated Pump: 2-inch Grundfos
Comments: Top Riser: 4" Schedule 40 PVC Casing.	



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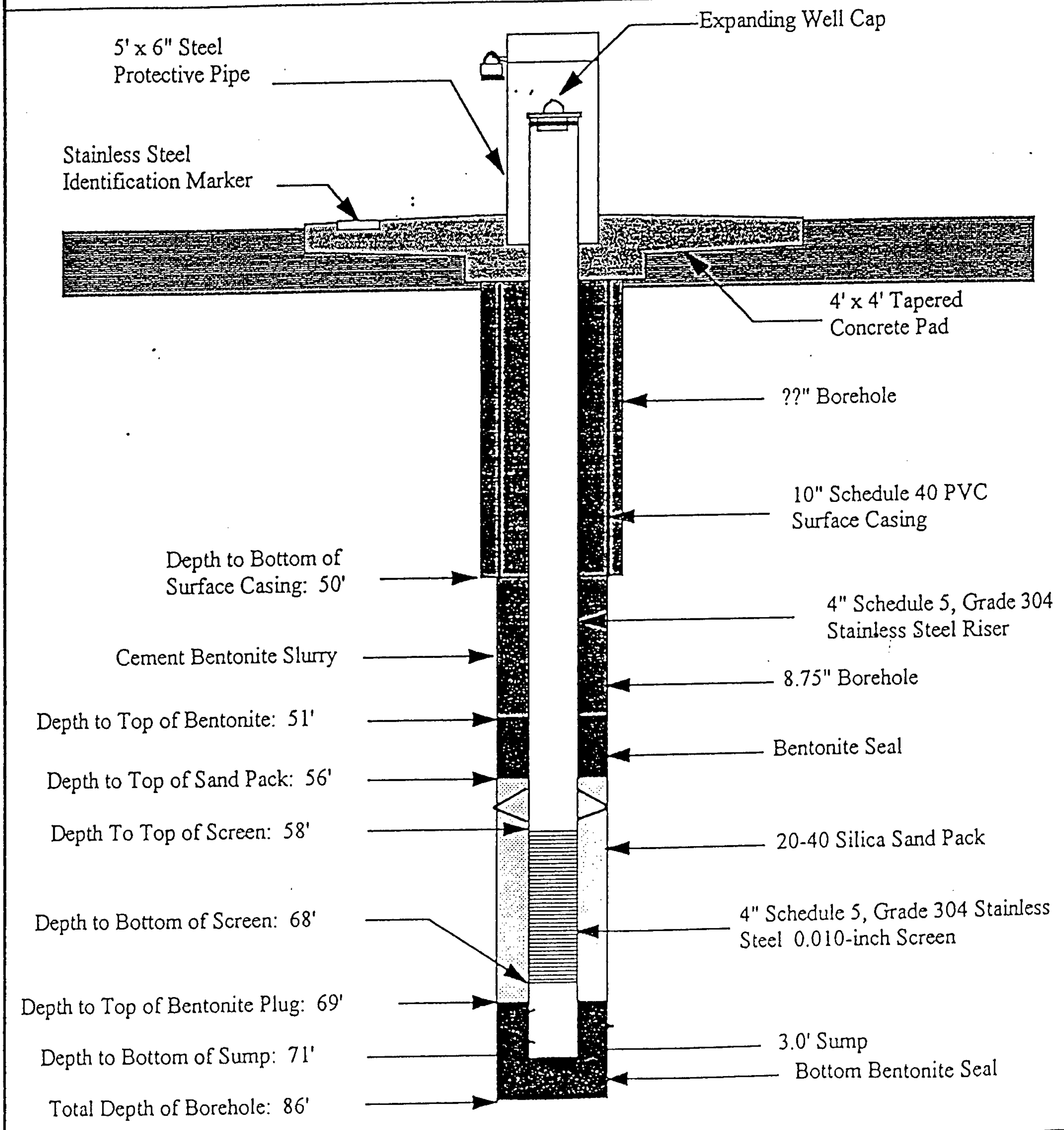
< > Centralizers

WELL CONSTRUCTION SCHEMATIC

Client: Tinker Air Force Base	Well ID: **2-152A**
Location: TAFB, Oklahoma	Site: BW
Contract No: F34650-94-D-0082/5004 (P & A 3)	Date 4-Inch Riser Set: 05/18/95
Contractor: Brown & Root Environmental	Drilling Method: Mud Rotary
Project Manager: David Parker	Ground Level Elev. (AMSL): 1243.63'
Project Geologist: James W. Roberts	Top of Csg. Elev. (AMSL): 1246.36'
Drlg Contractor: Associated Environmental Inc.	Dedicated Pump: 2-inch Grundfos
Comments: Top Riser: 4" Schedule 40 PVC Casing.	



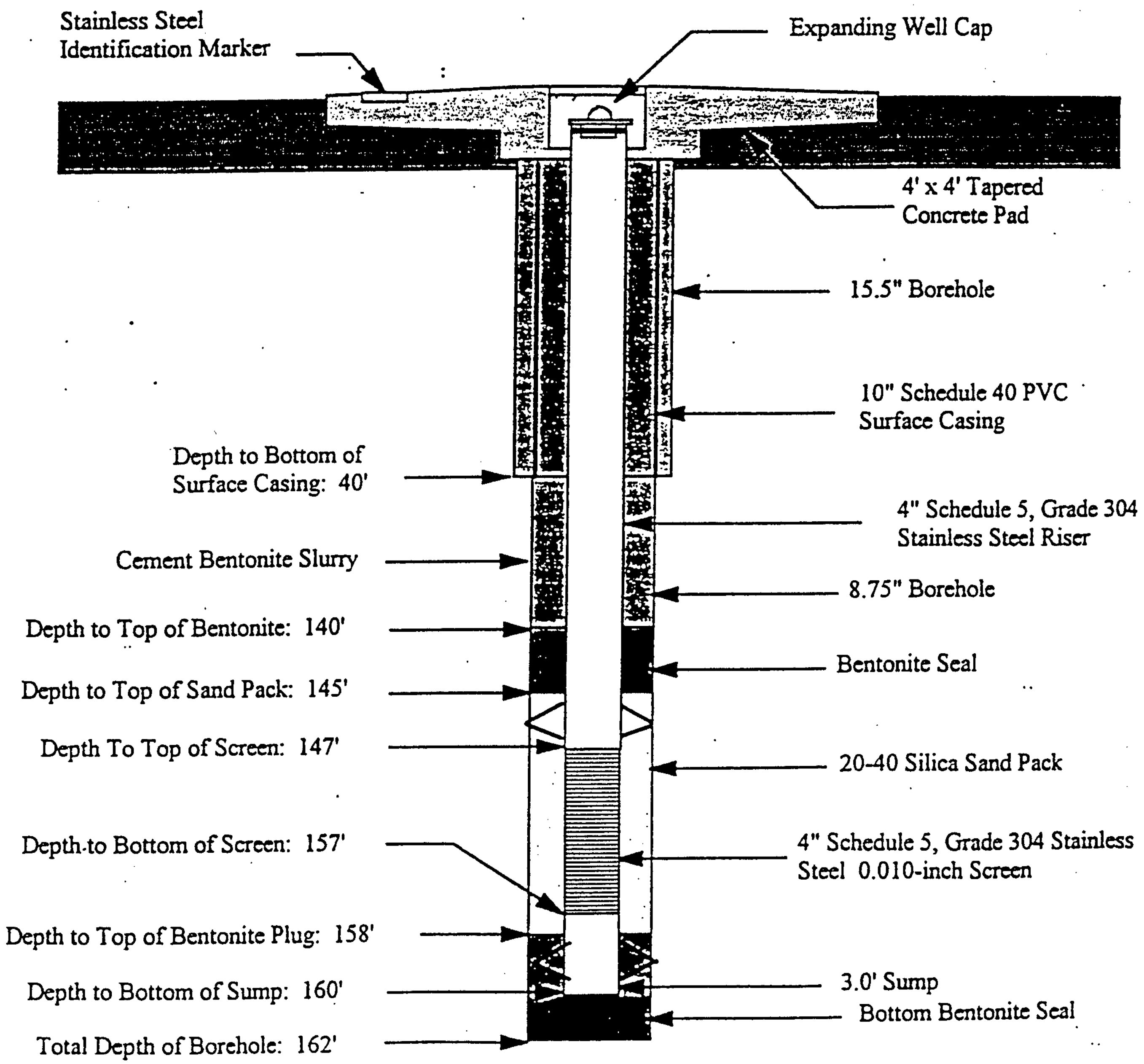
Drawing not to scale

Centralizers

WELL CONSTRUCTION SCHEMATIC

(2)

Client: Tinker Air Force Base	Well ID: 2-149C
Location: TAFB, Oklahoma	Site: PRM
Contract No: F34650-94-D-0082/5004 (P & A 3)	Date 4-Inch Riser Set: 06/06/95
Contractor: Brown & Root Environmental	Drilling Method: Mud Rotary
Project Manager: David Parker	Ground Level Elev. (AMSL): '
Project Geologist: James W. Roberts	Top of Csg. Elev. (AMSL): '
Drlg Contractor: Associated Environmental Inc.	Dedicated Pump: 2-inch Grundfos
Comments: Top Riser: 4" Schedule 40 PVC Casing	



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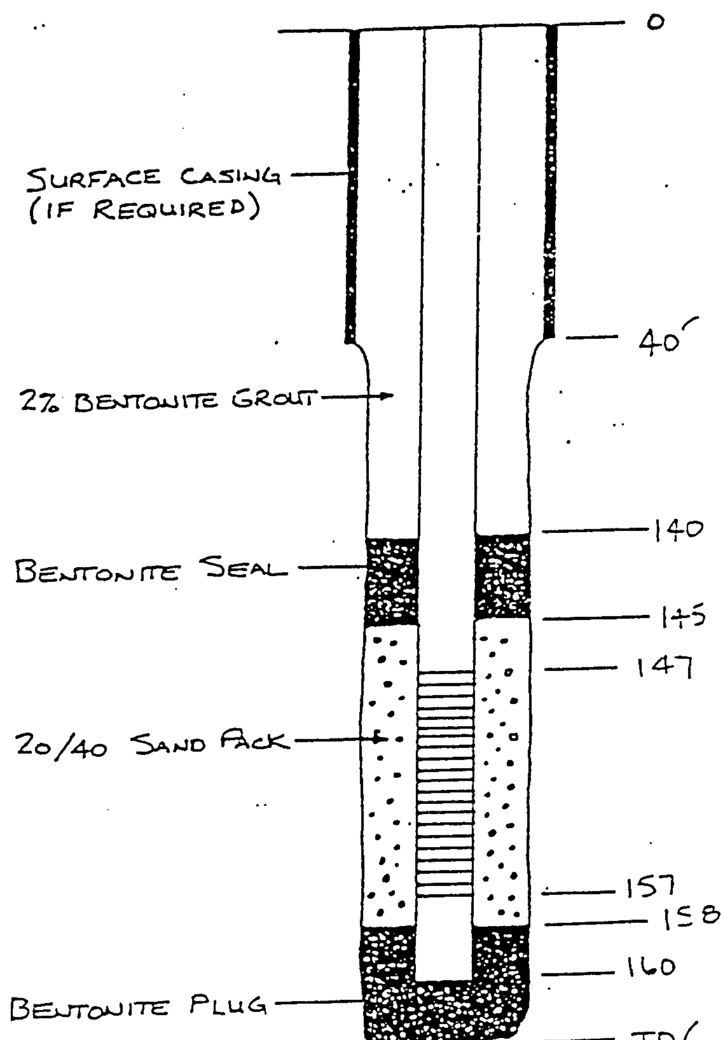
< > Centralizers

Well ID	Recommended Item	Construction Depth	Comments
2-1495	Surface Casing	0-40'	
	Inner Casing	—	
	Grout	0-140	
	Bentonite Seal (top)	140-145	
	Sand Pack	145-158	
	Bentonite Seal (bottom)	158-TD	
	Riser	0-147	
	Screen	147-157	
	Sump	157-160	



Log Received
6-5-95 5:30

Well Design Delivered
6-5-95 5:40

1 LOG RUN

2 LOG RUN

Client: TINKER AFB
Project Name: TINKER 5000

Project Location: TINKER AFB, OKLAHOMA
Project Number: 409802

SOIL BORING SB-0

DRILLING AND SAMPLING INFORMATION

Boring Location: AREA A

SURFACE ELEV.(FT): 1241.24 NGVD
TOTAL DEPTH(FT.): 25

Logged By: P. SCHUMANN, K. HERRINGTON
Date Started: 10/21/93

Drilled By: D. EYLER
NESCO
Date Completed: 10/22/93

Drill Rig Type: RODGERS 760
Drilling Method: HOLLOW STEM AUGER

Sampling Method: 5" I.D. CONTINUOUS SAMPLER

Notes: 8" DIAMETER BOREHOLE
COORDINATES–NAD 27: N 158461.461, E 2180256.673

DESCRIPTION	SAMPLE TYPE / SAMPLE NO.	IN. DRIVEN / IN. RECOVERED	FID	USCS
CLAY – moderately plastic; firm; dark reddish brown (5YR–3/3); dry – hard; (5YR–3/2) – reddish brown (5YR–4/6) – occasional pebbles; dark red (2.5YR–4/6)	A 1167	60 / 60	0 0 0 0 0 0 0 0 0	ch
SILTY CLAY – nonplastic; 50% silt; stiff; light blueish gray (5B–7/1); dry	A 1168	60	0	cl
CLAY – moderately plastic; hard; occasional pebbles; silty light blueish gray layers; dark red (2.5YR–4/6); dry – stiff; red (2.5YR–5/8)		60 / 60	0 0	ch
SILTY CLAY – nonplastic; 20% silt; firm; 3" discolored layer; gray (N6); strong gasoline odor	A 1170		5	cl
CLAY – moderately plastic; firm; occasional pebbles; red (2.5YR–5/8); dry		60	0 0 0	ch
SILTY CLAY – nonplastic; 20% silt; soft; red (10R–4/8); dry		60	0	cl
CLAY – moderately plastic; hard; increasing fines; gray silty layers; red (10R–4/8); moist; on odor	A 1171		6	cl
SAND – very fine grained; poorly graded; loose; increasing clay content with depth; light gray to reddish yellow (5YR–6/6); moist to wet – 10% to 20% clay; moderately graded; reddish yellow (5YR–6/6); no odor		60	0 0	ml
CLAY – slightly plastic; hard; reddish brown (5YR–4/4); dry	A 1172	60	0	ch
SILTY CLAY – slightly plastic; 20% silt; soft; red (2.5YR–5/8); wet; on odor			0	ch
CLAY – plastic; soft; red (2.5YR–5/8); moist; on odor			0	ch
SAND – very fine grained; 10% fines; moderately graded; loose; red (2.5YR–5/8); moist to wet; compact at 23'		48	0 0 0	sc

TOTAL DEPTH = 25.0 FEET

DRAFT BY	RPS 11/15/93	DRAFT CHK	PROJ. CHK	APPRV. BY	DWG. NO.	409802–A20 Sheet 1 of 1

Client: TINKER AFB
Project Name: TINKER 5000

Project Location: TINKER AFB, OKLAHOMA
Project Number: 409802

SOIL BORING SB-0[illegible]

DRILLING AND SAMPLING INFORMATION

Boring Location: AREA A

SURFACE ELEV.(FT): 1240.78 NGVD
TOTAL DEPTH(FT.): 20
Date Started: 10/25/93
Date Completed: 10/25/93

Logged By: P. SCHUMANN, K. HERRINGTON
Drilled By: D. EYLER
NESCO
Drill Rig Type: RODGERS 760
Drilling Method: HOLLOW STEM AUGER

Sampling Method: 5" I.D. CONTINUOUS SAMPLER

Notes: 8" DIAMETER BOREHOLE
COORDINATES—NAD 27: N 158291.785, E 2180348.712

DESCRIPTION	SAMPLE TYPE / SAMPLE NO.	IN. DRIVEN / IN. RECOVERED	FID	USCS	GRAPHIC LOG
SILTY CLAY – slightly plastic; 20% silt; soft; small gravel layer at 1'; strong brown (2.5YR-4/6); dry		60	0, 0	ol	
– highly plastic; hard; yellowish red (5YR-4/6); moist			0		
– moderately plastic; firm; dark olive brown (2.5Y-3/3)	A 1173		0		
CLAY – highly plastic; hard; dark olive brown (2.5Y-3/3); moist		48	0, 0	ch	
– stiff; olive brown streaks; yellowish red (5YR-5/6)		60	5, 12		
– hard			60, 50		
– some 1" greenish gray layers; strong odor	A 1174	48	60		
– firm; dark red (2.5YR-4/8)		60	400, 80		
SAND – very fine grained; 20% fines; moderately graded; compact; some grayish green streaking; reddish yellow (5YR-6/8); moist; gasoline odor	A 1175		150, 5000	sc	
– 10% fines; poorly graded; loose; saturated with product (gasoline)		52			
– 15% fines; moderately graded; yellowish red (5YR-5/8); wet; slight product odor	A 1176	60	30, 5		
– sample lost during removal		24			

TOTAL DEPTH = 20.0 FEET

DRAFT BY	RPS 11/16/93	DRAFT CHK		PROJ. CHK		APPRV. BY		DWG. NO.	409802–A21 Sheet 1 of 1

Client: TINKER AFB
Project Name: TINKER 5000

Project Location: TINKER AFB, OKLAHOMA
Project Number: 409802

SOIL BORING SB-0(

DRILLING AND SAMPLING INFORMATION

Boring Location: AREA A

SURFACE ELEV.(FT): 1240.43 NGVD
TOTAL DEPTH(FT.): 18
Date Started: 10/25/93
Date Completed: 10/26/93

Logged By: P. SCHUMANN, K. HERRINGTON
Drilled By: D. EYLER
NESCO
Drill Rig Type: RODGERS 760
Drilling Method: HOLLOW STEM AUGER

Sampling Method: 5" I.D. CONTINUOUS SAMPLER

Notes: 8" DIAMETER BOREHOLE
COORDINATES—NAD 27: N 158257.819, E 2180317.691

DESCRIPTION	SAMPLE TYPE / SAMPLE NO.	IN. DRIVEN / IN. RECOVERED	FID	USCS	GRAPHIC LOG
CLAYEY SILT – 30% clay; organics; moderately graded; loose; dark yellowish brown grading to		60	0	ol	
to yellowish red (10YR-4/4); dry			0	ch	
SILTY CLAY – moderately plastic; 10% silt; stiff; brown (7.5YR-4/4); dry			0		
	A 1177		0		
SAND – very fine to medium grained; moderately graded; loose; red (2.5YR-5/8); moist			0	sp	
		40	2		
– wet		60	6		
SILTY GRAVELLY CLAY – highly plastic; 10% silt, 10% gravel; soft; dark gray (N4) streaking;			20	ch	
red (2.5YR-5/8); moist			80		
– stiff	A 1178		200		
– slightly plastic; 5% silt, 5% gravel; soft; red (2.5YR-5/8); dry; strong product odor		48	4000		
SILTY CLAY – moderately plastic; 20% silt; soft; red (2.5YR-5/8); moist; strong product odor	A 1179	60	2000	cl	
			60		
SILTY GRAVELLY CLAY – slightly plastic; 5% silt, 5% gravel; hard; dark gray streaks; red (2.5YR-5/8);			20	cl	
dry; strong product odor			20		
SAND – very fine grained; poorly graded; compact; red (2.5YR-5/8); moist		60 / 36	50	sp	
SILTY CLAY – nonplastic; 10% silt; soft; red (2.5YR-5/8); moist; strong product odor			20	cl	
SAND – very fine grained; poorly graded; loose; red (2.5YR-5/8); moist	A 1180		10	sp	
– very fine to fine grained; wet		36			

TOTAL DEPTH = 18.0 FEET

DRAFT BY	RPS 11/16/93	DRAFT CHK		PROJ. CHK		APPRV. BY		DWG. NO.	409802–A22 Sheet 1 of 1

Table 5-1
Upper Saturated Zone
Monitoring Well Water Levels
Area A Service Station

Well Number	Top of Casing Elevation (ft. NGVD)	Date Measured	Static Depth of Groundwater (ft. btoc)	Elevation of Water Level (ft. NGVD)	Measured Depth of HC (ft.btoc)	Thickness of HC
2-50B	1241.30	1/31/94	15.02	1226.28		
		2/6/94	14.83	1226.47	14.82	0.01
		9/6/94	16.82	1226.19	16.82	1.97
		11/2/94	15.12	1226.18	14.85	0.27
		7/14/95	15.30	1226.00		
2-51B	1241.29	2/6/94	11.09	1230.20		
		9/6/94	10.92	1230.37		
		11/2/94	11.32	1229.97		
		1/9/95	11.55	1229.74		
		7/14/95	10.15	1231.14		
2-52B	1241.81	2/6/94	14.11	1227.70		
		9/6/94	14.79	1227.02		
		11/2/94	14.45	1227.36		
		1/9/95	15.02	1226.79		
		7/14/95	14.15	1227.66		
2-2	1242.27	1/9/94	14.00	1228.27		
		9/6/94	15.63	1226.64		
2-2	1241.99	11/2/94	15.33	1226.94		
		1/9/95	15.38	1226.89		
		7/14/95	15.34	1226.65		
2-3	1242.38	1/19/94	15.75	1226.63		
		9/6/94	16.41	1225.97		
2-3	1242.34	11/3/94	16.26	1226.08		
		1/9/95	16.38	1225.96		
		7/14/95	15.79	1226.55		
2-4	1243.16	1/18/94	19.60	1223.56		
		9/6/94	20.89	1226.04	16.55	4.34
		11/2/94	17.54	1225.62	16.73	0.81
		1/9/95	20.71	1222.45		
		7/14/95	19.3	1223.86		
2-145B	1242.75	7/13/95	10.09	1232.66		
2-146B	1240.70	7/11/95	10.29	1230.41		
2-149B	1236.55	7/11/95	18.20	1218.35		
2-163B	1237.10	7/14/95	13.25	1223.85		
2-164B	1238.94	7/14/95	13.47	1225.47		

Table 5-1 (continued)
Upper Saturated Zone
Monitoring Well Water Levels
Area A Service Station

Well Number	Top of Casing Elevation (ft. NGVD)	Date Measured	Static Depth of Groundwater (ft. btoc)	Elevation of Water Level (ft. NGVD)	Measured Depth of HC (ft.btoc)	Thickness of HC
2-165B	1223.60	7/14/95	5.07	1218.53		
2-166B	1244.97	7/14/95	17.96	1227.01		

Where free-phase hydrocarbon is present, the water level has been corrected using the formula:

C = (SG x T) + M

Where: C = corrected water level
SG = specific gravity of hydrocarbon, assume = 0.87
T = hydrocarbon thickness
M = measured water level

Table 5-4
Lower Saturated Zone Monitoring Well Water Levels Area A Service Station

Well Number	Top of Casing Elevation (ft. NGVD)	Date Measured	Static Depth of Groundwater (ft. btoc)	Elevation of Water Level (ft. NGVD)
2-2A	1242.96	1/31/94	45.56	1197.40
		2/6/94	45.05	1197.91
		9/6/94	46.35	1196.61
		11/2/94	45.15	1196.81
		1/9/95	46.56	1196.40
		7/14/95	46.19	1196.77
2-4A	1240.81	1/31/94	43.17	1197.64
		2/6/94	42.65	1198.16
		9/6/94	43.93	1196.88
		11/2/94	43.69	1197.12
		1/9/95	44.13	1196.68
		7/14/95	43.74	1197.07
2-51A	1241.65	1/31/94	43.91	1197.74
		2/6/94	44.40	1197.25
		9/6/94	44.52	1197.13
		11/2/94	44.44	1197.21
		1/9/95	44.74	1196.91
		7/14/95	44.33	1197.32
2-52A	1241.98	1/31/94	44.78	1197.20
		2/6/94	44.28	1197.70
		9/6/94	45.56	1196.42
		11/2/94	45.36	1196.62
		1/9/95	45.72	1196.26
		7/14/95	45.40	1196.58
2-149A	1236.72	7/11/95	41.27	1195.45

Table 5-2
Slug Test Results
Area A Service Station

Upper Saturated Zone

Well No.	Thickness (ft)	Cooper et al. T (ft2/min)	Cooper et al. K(cm/sec)	Cooper et al. K(ft/min)	Cooper et al. K(ft/day)	Bouwer&Rice K(cm/sec)	Bouwer&Rice K(ft/min)	Bouwer&Rice K(ft/day)
2-50B		Method not applicable				1.3E-03	0.0025	3.6
2-51B		Method not applicable				1.4E-05	0.000028	0.04
2-52B		Method not applicable				1.9E-04	0.00038	0.55
Average Value		Method not applicable				4.9E-04	0.00097	1.4

Lower Saturated Zone

Well No.	Thickness (ft)	Cooper et al. T (ft2/min)	Cooper et al. K(cm/sec)	Cooper et al. K(ft/min)	Cooper et al. K(ft/day)	Bouwer&Rice K(cm/sec)	Bouwer&Rice K(ft/min)	Bouwer&Rice K(ft/day)
2-2A	12.5	0.0069	2.8E-04	0.00055	0.79	1.9E-04	0.00037	0.53
2-4A	8	0.065	4.1E-03	0.0081	11	7.0E-04	0.0014	2.0
2-51A(slug in)	17	0.097	2.9E-03	0.0057	8.2	6.9E-04	0.0014	1.9
2-51A(slug out)	16.5	0.064	2.0E-03	0.0038	5.5	6.7E-04	0.0013	1.9
2-52A(slug in)	24.3	0.069	1.4E-03	0.0028	4.0	5.3E-04	0.0010	1.5
2-52A(slug out)	16	0.022	6.9E-04	0.0013	1.9	5.1E-04	0.0010	1.4
Average Value		5.4E-02	1.9E-03	3.7E-03	5.3E+00	5.5E-04	1.1E-03	1.6E+00

Analysis performed with AQTESOLV software
T - Transmissivity (based on Cooper et al methodology for confined aquifers)
K - Hydraulic Conductivity (based on Bouwer-Rice and Cooper et al.)
ft - feet; cm - centimeters; sec - seconds; min - minutes

Table 5-7
Analytical Results for Soil Samples
Borings 1-S1 Thru 1-S5
Area A Service Station

		Benzene (ug/kg)	Toluene (ug/kg)	Ethylbenzene (ug/kg)	Xylenes (ug/kg)	Total BTEX[1] (ug/kg)	TPH (mg/kg)	Total Lead (mg/kg)
OCC Category II Cleanup Standards		5,000	400,000	150,000	1,000,000	1,555,000	500	26[2]
Boring Number	Sample Depth (Feet)							
1-S1	10	950,000	1,600,000	500,000	1,500,000	4,550,000	6,300	<.002
	12	1,000,000	1,700,000	300,000	950,000	3,950,000	11,000	148
1-S2	5	<2	<2	<2	<2	<8	<10	22.8
	10	5,600	61,000	19,000	110,000	195,600	500	10.5
	15	1,000,000	2,000,000	510,000	1,600,000	5,110,000	8,000	10.4
1-S3	10	1,000,000	1,600,000	430,000	1,200,000	4,230,000	12,000	8.99
	15	59,000	380,000	77,000	460,000	976,000	9,600	8.7
1-S4	10	300,000	1,700,000	430,000	2,400,000	4,830,000	85,000	9.77
	15	1,200,000	2,300,000	570,000	1,900,000	5,970,000	86,000	19.4
1-S5	10	<50	1,700	1,100	8,500	11,350	160	12.1
	15	13,000	61,000	17,000	110,000	201,000	860	9.1

Source: ERI, 1990.
Samples Collected May 23-30, 1990
Shaded results indicate exceedance of OCC Cleanup Standards or Background
BTEX - (Benzene, Toluene, Ethylbenzene, Xylenes) by Method 8020
TPH - Total Petroleum Hydrocarbons by Method 418.1
Total Lead By Method 6010
[1]Total BTEX computed by summation of BTEX compounds
[2]Background concentration (IT, 1995b)

Table 5-8
Analytical Results for Soil Samples
Borings SB-1 Thru SB-8
Area A Service Station

		Benzene (ug/kg)	Toluene (ug/kg)	EthylBenzene (ug/kg)	Xylenes (ug/kg)	Total BTEX[1] (ug/kg)	TPH (mg/kg)	Total Lead (mg/kg)
OCC Category II Cleanup Standards		5,000	400,000	150,000	1,000,000	1,555,000	500	26[2]
Boring Number	Sample Depth (Feet)							
SB-1	12-15	26,400	140,000	63,300	247,000	476,700	6170	13.5(.7*)
	15-17	12,300	109,000	53,800	215,000	390,100	3140	7.6(.4*)
	19	ND	322	187	1080	1,589	ND	ND
SB-2	3	1.0(E)	1.7	ND		2.70	11.2(.6*)	
	6	8.1	ND	ND	ND	8.1	ND	7.4(.4*)
	9	126	669	422	1810	3,027	23.7	11.3(.6*)
	12	824(E)	13,400	6680	37,900	58,804	73.7	7.7(.4*)
	15	ND	9020	7380	46,700	63,100	58.4	ND
	18	ND	1.9	ND	ND	1.9	15.6	ND
	21	1.2	2.9	0.7(E)	2.3	7.10	ND	ND
SB-3	2.5-5.5	ND	ND	ND	ND	ND	ND	6.1(.3*)
	5.5-7	ND	1.7	1.8	12.5	16.0	ND	ND
	8	ND	1440	2050	13,600	17,090	42.3	ND
	11	1720	23,600	17,000	90,300	132,620	1040	6.2(.3*)
	13.5-16	705(E)	18,300	10,500	59,200	88,705	412	ND
	19	257	237	24.5	106	624.50	ND	ND
SB-4	3	2.0	0.5(E)	ND	1.1	3.60	ND	13.0(.7*)
	6	35.8	2.2	1.0(E)	3.0	42.00	ND	17.4(.9*)
	9	1110(E)	6790	3590	12,700	24,190	161.1	4.7(.2*)
	12	ND	10,700	9740	42,700	63,140	280	ND
	15	ND	ND	ND	0.8(E)	0.8	ND	ND
SB-5	3	3.0	3.1	19.2	16.6	41.90	ND	12.7(.6*)
	6	ND	ND	ND	ND	ND	ND	6.1(.3*)
	7-9	ND	390	876	2000	3,266	43.2	8.7(.4*)
	12	ND	ND	ND	ND	ND	ND	6.2(.3*)
	15	ND	ND	ND	ND	ND	ND	ND
	18	ND	ND	ND	ND	ND	ND	ND
	21	ND	ND	ND	ND	ND	ND	ND
SB-6	3	ND	ND	ND	ND	ND	ND	13.7(.7*)
	6	ND	ND	ND	ND	ND	ND	7.9(.4*)
	10-12	ND	10,100	8040	44,700	62,840	310	16.9(.8*)
	12-17	6.0	ND	ND	7.6	13.60	ND	ND
	21-22	ND	ND	ND	ND	ND	ND	ND
	22-23	5.6	6.0	2.7	10.0	24.30	ND	ND
	23-24	1.8	2.2	ND	2.3	6.30	ND	ND
SB-7	2-7	ND	ND	ND	ND	ND	ND	12.3(.6*)
	9-12	ND	ND	ND	ND	ND	114	7.8(.4*)
	12-15	ND	ND	ND	ND	ND	12.1	ND
	15-17	0.9(E)	ND	ND	ND	0.9	ND	ND
	17-20	ND	ND	ND	ND	ND	ND	5.4(.3*)
	20-22	ND	1.0(E)	ND	ND	1.0	ND	ND
	22-23	1.2	ND	ND	ND	1.2	ND	ND
SB-8	3	ND	ND	ND	ND	ND	ND	10.8(.5*)
	7	ND	ND	ND	ND	ND	ND	9.6(.5*)
	9	ND	ND	ND	0.7(E)	0.7	ND	6.3(.3*)
	12	ND	ND	14.7	27	41.70	14.1	6.3(.3*)
	15	ND	ND	1.3	2.7	4.00	ND	4.4(.2*)
	15-17	ND	ND	ND	ND	ND	ND	ND
	20	ND	ND	ND	ND	ND	ND	ND
	22-25	5.8	ND	ND	ND	5.8	ND	4.3(.2*)

Source: WSCI, 1992; Samples Collected May 20-23, 1991
Shaded results indicate exceedance of OCC Cleanup Standards or Background
BTEX - (Benzene, Toluene, Ethylbenzene, Xylenes) by Method 8020
TPH - Total Petroleum Hydrocarbons by Method 8015 Modified
Total Lead By Method 6010

* - Equivalent Concentration by TCLP Extraction Method
ND - Not Detected at the Practical Quantitation Limit
E - Estimated Concentration
[1]Total BTEX computed by summation of BTEX compounds
[2]Background concentration (IT, 1995b)

Table 5-9
Analytical Results for Soil Samples
1993/94 Investigation
Area A Service Station

Well Number: / Sample Number: / Depth:	Background/Cleanup Levels		SB-006 A1312 4 - 5		SB-006 A1313 9 - 10		SB-006 A1315 12 - 13		SB-006 A1316 17 - 18		SB-006 A1317 20 - 21	
Parameters	Background[1]	OCC Cat. II[2]	Result	QFR	Result	QFR	Result	QFR	Result	QFR	Result	QFR
Metals (mg/kg)												
Arsenic	23		4.5	N	2.3	N			1.0	N	2.1	N
Barium	1,770		310	N	75	N	600				140	
Cadmium	0.58		1.6		1.3						0.98	
Chromium	34		20		19		15		12		79	
Lead	26		11		5.6		1.4	N	0.76	N	2.9	N
Zinc	52		24		21		19		4.2		18	
Semi-Volatiles (mg/kg)												
Di-n-octylphthalate			0.083	JB			0.17	JB				
Volatiles (μg/kg)												
1,2-Dichloroethane											1.6	J
2-Butanone									5.5	JB	25	JB
Acetone			13	JB	10	JB	18	JB	19	JB	49	JB
Benzene		5,000									1.8	J
Chlorobenzene									0.4	J		
Ethylbenzene		150,000							0.2	J		
Methylene Chloride			12	B	11	B	7.7	JB	0.7	JB	1.2	JB
Toluene		400,000									1.6	J
Trichloroethene											2.8	J
Xylenes (total)		1,000,000									1.3	JB
cis-1,2-Dichloroethene											8.8	

Source: IT Corporation, 1995c; Sampling conducted October 1993 through January 1994
Note: Appendix IX constituents are listed where the analytical results are above any of the listed action levels or the method quantitation limit
[1]Background metals concentration developed by IT Corporation (1995b)
[2]Oklahoma Corporation Commission (OCC) Category II Clean-up Levels

<u>Qualifier (QFR) Codes</u>

N = Sample is outside of Matrix Spike QC limit
VOCs/SVOCs: B = Analyte is found in the associated blank as well as in the sample
J = Concentration is an estimated value

Table 5-9 (continued)
Analytical Results for Soil Samples
1993/94 Investigation
Area A Service Station

Well Number: / Sample Number: / Depth:	Background/Cleanup Levels		SB-007 A1318 3 - 4		SB-007 A1319 9 - 10		SB-007 A1175 14 - 15		SB-007 A1176 15 - 16		SB-008 A1177 3 - 4	
Parameters	Background[1]	OCC Cat. II[2]	Result	QFR	Result	QFR	Result	QFR	Result	QFR	Result	QFR
General Parameters (mg/kg)												
Total Petroleum Hydrocarbons		500			16		92					
Metals (mg/kg)												
Arsenic	23		2.5		1.1						1.4	
Barium	1,770		110	N	260	N	80		48	N	43	N
Cadmium	0.58				0.68							
Chromium	34		8.6		17		3.8		5.2		4.6	
Lead	26		7.0		6.6		2.0		1.5		3.0	
Zinc	52		13		19		3.9		6.3		8.1	
Semi-Volatiles (mg/kg)												
2-Methylnaphthalene					0.40		1.5					
Fluorene							0.057	J				
Naphthalene					0.36		1.5					
Phenanthrene							0.14	J				
Volatiles (µg/kg)												
2-Butanone					77	JB	100	JB	19	JB		
Acetone					190	JB	140	JB	35	JB	7.2	JB
Ethylbenzene		150,000			1600	D	24000	D	2.7	J	2.3	J
Methylene Chloride			2.0	JB								
Toluene		400,000					4000	D	1.1	J	1.0	J
Xylenes (total)		1,000,000			3000	D	95000	D	9.7		9.1	

Source: IT Corporation, 1995c; Sampling conducted October 1993 through January 1994
Note: Appendix IX constituents are listed where the analytical results are above any of the listed action levels or the method quantitation limit
[1]Background metals concentration developed by IT Corporation (1995b)
[2]Oklahoma Corporation Commission (OCC) Category II Clean-up Levels
Qualifier (QFR) Codes
N = Sample is outside of Matrix Spike QC limit
D = Compound identified at a secondary dilution factor
VOCs/SVOCs: B = Analyte is found in the associated blank as well as in the sample
J = Concentration is an estimated value

Table 5-9 (continued)
Analytical Results for Soil Samples
1993/94 Investigation
Area A Service Station

Well Number: / Sample Number: / Depth:	Background/Cleanup		SB-008 A1178 9 - 10		SB-008 A1179 10 - 11		SB-008 A1180 17 - 18		2-2A A1354 2 - 2.5		2-2A A1355 8.5 - 9	
Parameters	Background[1]	OCC Cat. II[2]	Result	QFR	Result	QFR	Result	QFR	Result	QFR	Result	QFR
General Parameters (mg/kg)												
Total Petroleum Hydrocarbons		500			24						1,100	
Metals (mg/kg)												
Arsenic	23				2.9	N			2.6	N		
Barium	1,770		110	N*	160	N*	17	N*	240	N*	360	N*
Cadmium	0.58		0.68		1.1							
Chromium	34		12	*	21	*	6.9	*	15		21	
Lead	26		4.5	N	9.2	N	1.9	N	11	N	5.1	N
Zinc	52		14	*	22	*	7.8	*	25		14	
Semi-Volatiles (mg/kg)												
2-Methylnaphthalene					0.77						17	
Acenaphthene											0.52	J
Dibenzofuran											0.36	J
Fluorene											0.85	J
Naphthalene					0.53						14	
Phenanthrene											2.2	
Pyrene											0.19	J
Volatiles (µg/kg)												
2-Butanone			23	J	76	J	6.5	J			2200	JB
Acetone			55	JB	160	JB	24	JB	8.0	JB		
Ethylbenzene		150,000	1.9	J	540						49000	D
Methylene Chloride			8.5	JB	7.1	JB	7.9	JB	1.7	JB		
Toluene		400,000			19	J						
Xylenes (total)		1,000,000	1.5	JB	2700	B					84000	D

Source: IT Corporation, 1995c; Sampling conducted October 1993 through January 1994
Note: Appendix IX constituents are listed where the analytical results are above any of the listed action levels or the method quantitation limit
[1]Background metals concentration developed by IT Corporation (1995b)
[2]Oklahoma Corporation Commission (OCC) Category II Clean-up Levels
Qualifier (QFR) Codes
N = Sample is outside of Matrix Spike QC limit
D = Compound identified at a secondary dilution factor
Metals: * = Duplicate analysis outside control limits
VOCs/SVOCs: B = Analyte is found in the associated blank as well as in the sample
J = Concentration is an estimated value

Table 5-9 (continued)
Analytical Results for Soil Samples
1993/94 Investigation
Area A Service Station

Well Number: / Sample Number: / Depth:	Background/Cleanup		2-2A A1356 10.5 - 11		2-4A A1358 4 - 5		2-4A A1359 8.5 - 9		2-4A A1360 12 - 13		2-50B A1341 3 - 4	
Parameters	Background[1]	OCC Cat. II[2]	Result	QFR	Result	QFR	Result	QFR	Result	QFR	Result	QFR
General Parameters (mg/l)												
Total Petroleum Hydrocarbons		500	340		110		61		99			
Metals (mg/kg)												
Arsenic	23		1.1	N	2.3						2.5	
Barium	1,770		97	N*	370	N*	160	N*	870	N*	160	N
Cadmium	0.58				0.68						0.47	
Chromium	34		15		14		10		6.3		11	
Lead	26		4.7	N	13		3.5		2.0		7.6	
Zinc	52		15		21		10		5.4		17	
Semi-Volatiles (mg/kg)												
2-Methylnaphthalene			3.3				0.92		4.9			
Acenaphthene			0.24	J					0.04	J		
Anthracene			0.085	J								
Dibenzofuran			0.16	J								
Fluorene			0.35						0.03	J		
Naphthalene			1.3				0.96		4.4			
Phenanthrene			0.95						0.07	J		
Pyrene			0.07	J								
bis(2-Ethylhexyl)phthalate					0.18	J	0.07	J				
Volatiles (µg/kg)												
2-Butanone			20	JB	200	JB	16	JB	5100	JB	7.3	JB
Acetone			110	B	600	B	28	JB			11	JB
Benzene		5,000			87							
Chlorobenzene									370	J		
Ethylbenzene		150,000	250	D	110		240		18,000		0.8	J
Methylene Chloride			5.9	JB			5.2	JB			1.0	JB
Toluene		400,000			89	B	1.4	JB	12,000	B	1.0	J
Xylenes (total)		1,000,000	44		270		1600		10,000	D	1.4	J

Source: IT Corporation, 1995c; Sampling conducted October 1993 through January 1994

Note: Appendix IX constituents are listed where the analytical results are above any of the listed action levels or the method quantitation limit

[1]Background metals concentration developed by IT Corporation (1995b)

[2]Oklahoma Corporation Commission (OCC) Category II Clean-up Levels

Qualifier (QFR) Codes

N = Sample is outside of Matrix Spike QC limit

D = Compound identified at a secondary dilution factor

Metals: * = Duplicate analysis outside control limits

VOCs/SVOCs: B = Analyte is found in the associated blank as well as in the sample

J = Concentration is an estimated value

Table 5-9 (continued)
Analytical Results for Soil Samples
1993/94 Investigation
Area A Service Station

Well Number: Sample Number: Depth:	Background/Cleanup		2-50B A1342 9 - 10		2-50B A1343 10 - 12		2-51A A1350 1 - 1.5	
Parameters	Background[1]	OCC Cat. II[2]	Result	QFR	Result	QFR	Result	QFR
General Parameters (mg/kg)								
Total Petroleum Hydrocarbons		500	44		11		30	
Metals (mg/kg)								
Arsenic	23		1.8		2.8		2.1	N
Barium	1,770		92	N	230	N	110	
Cadmium	0.58				1.4			
Chromium	34		19		24		14	
Lead	52		3.2		6.0		7.4	N
Zinc	79		24		29		14	
Semi-Volatiles (mg/kg)								
2-Methylnaphthalene			0.62		0.55			
Di-n-butylphthalate					0.049	J		
Naphthalene			0.44		0.36			
bis(2-Ethylhexyl)phthalate							0.047	J
Volatiles ($\mu g/kg$)								
2-Butanone			83	JB	33	JB		
Acetone			290	JB	170	JB	6.2	JB
Benzene		5,000					1.0	JB
Ethylbenzene		150,000	250		64			
Methylene Chloride							2.7	JB
Toluene		400,000	100		12			
Xylenes (total)		1,000,000	1200		440			

Source: IT Corporation, 1995c; Sampling conducted October 1993 through January 1994
Note: Appendix IX constituents are listed where the analytical results are above any of the listed action levels or the method quantitation limit
[1]Background metals concentration developed by IT Corporation (1995b)
[2]Oklahoma Corporation Commission (OCC) Category II Clean-up Levels
Qualifier (QFR) Codes
N = Sample is outside of Matrix Spike QC limit
VOCs/SVOCs: B = Analyte is found in the associated blank as well as in the sample
J = Concentration is an estimated value

Table 5-9 (continued)
Analytical Results for Soil Samples
1993/94 Investigation
Area A Service Station

Well Number: / Sample Number: / Depth:	Background/Cleanup		2-51A A1351 6 - 6.5		2-51A A1352 12 - 12.5		2-51A A1353 18 - 18.5		2-51B A1334 6 - 7		2-51B A1335 9 - 10	
Parameters	Background[1]	OCC Cat. II[2]	Result	QFR	Result	QFR	Result	QFR	Result	QFR	Result	QFR
General Parameters (mg/kg)												
Total Petroleum Hydrocarbons		500									24	
Metals (mg/kg)												
Arsenic	23		4.9	N	1.9	N	1.5	N	14	N	5.5	N
Barium	1,770		810		62		180		280	N	5000	N
Cadmium	0.58		0.73						1.6		0.58	
Chromium	34		12		16		12		16		16	
Lead	26		8.2	N	6.2	N	4.1	N	22		9.0	
Selenium	8.2								16			
Zinc	52		16		17		12		23		23	
Semi-Volatiles (mg/kg)												
Di-n-octylphthalate									0.38	B	0.27	JB
Volatiles ($\mu g/kg$)												
2-Butanone			7.4	JB	5.2	JB	5.8	JB				
Acetone			20	JB	13	JB	11	JB	5.1	JB	32	JB
Benzene		5,000	1.0	JB								
Chlorobenzene									0.5	J		
Ethylbenzene		150,000							0.2	J		
Methylene Chloride			2.4	JB	2.2	JB	13	B	6.6	JB	13	B

Source: IT Corporation, 1995c; Sampling conducted October 1993 through January 1994
Note: Appendix IX constituents are listed where the analytical results are above any of the listed action levels or the method quantitation limit
[1]Background metals concentration developed by IT Corporation (1995b)
[2]Oklahoma Corporation Commission (OCC) Category II Clean-up Levels

Qualifier (QFR) Codes

N = Sample is outside of Matrix Spike QC limit
VOCs/SVOCs: B = Analyte is found in the associated blank as well as in the sample
J = Concentration is an estimated value

Table 5-9 (continued)
Analytical Results for Soil Samples
1993/94 Investigation
Area A Service Station

Well Number: / Sample Number: / Depth:	Background/Cleanup		2-51B A1336 11 - 12		2-52A A1347 1 - 2		2-52A A1348 8 - 9		2-52A A1349 10 - 10.5		2-52B A1338 4 - 5	
Parameters	Background	OCC Cat. II[1]	Result	QFR	Result	QFR	Result	QFR	Result	QFR	Result	QFR
General Parameters (mg/kg)												
Total Petroleum Hydrocarbons		500	84						19			
Metals (mg/kg)												
Arsenic	23				2.4	N	4.4	N	1.8	N	2.8	N
Barium	1,770		63	N	160	N	120	N	120	N	260	
Cadmium	0.58		0.58								1.0	
Chromium	34		12		12	*	13	*	19	*	15	
Chromium VI	0.16										0.42	
Lead	26		5.5		11	N	7.1	N	6.7	N	8.0	N
Zinc	52		14		21	*	15	*	19	*	25	
Semi-Volatiles (mg/kg)												
2-Methylnaphthalene			0.19	J					1.1			
Di-n-octylphthalate			0.24	JB							0.07	JB
Naphthalene			0.13	J					0.88			
Volatiles (µg/kg)												
2-Butanone			21	JB	3.1	JB			40	JB		
Acetone			76	JB	12	JB	17	JB	100	B		
Benzene		5,000			4.8	J			47			
Ethylbenzene		150,000	4.9	J					92			
Methylene Chloride			0.9	JB	2.9	JB	3.2	JB	4.8	JB	8.3	JB
Xylenes (total)		1,000,000	65	B					71			

Source: IT Corporation, 1995c; Sampling conducted October 1993 through January 1994
Note: Appendix IX constituents are listed where the analytical results are above any of the listed action levels or the method quantitation limit
[1]Background metals concentration developed by IT Corporation (1995b)
[2]Oklahoma Corporation Commission (OCC) Category II Clean-up Levels

Qualifier (QFR) Codes

N = Sample is outside of Matrix Spike QC limit
Metals: * = Duplicate analysis outside control limits
VOCs/SVOCs: B = Analyte is found in the associated blank as well as in the sample
J = Concentration is an estimated value

Table 5-9 (continued)
Analytical Results for Soil Samples
1993/94 Investigation
Area A Service Station

Well Number: / Sample Number: / Depth:	Background/Cleanup		2-52B A1339 5.5 - 7		2-52B A1340 12 - 13	
Parameters	Background	OCC Cat. II[1]	Result	QFR	Result	QFR
Metals (mg/kg)						
Arsenic	23		2.9	N	1.5	N
Barium	1,770		320		76	
Cadmium	0.58		0.79		1.1	
Chromium	34		16		16	
Lead	26		6.8	N	5.3	N
Zinc	52		22		18	
Semi-Volatiles (mg/kg)						
Di-n-octylphthalate			0.15	JB	0.31	JB
Volatiles (μg/kg)						
Acetone			17	JB	10	JB
Methylene Chloride			7.6	JB	7.6	JB

Source: IT Corporation, 1995c; Sampling conducted October 1993 through January 1994
Note: Appendix IX constituents are listed where the analytical results are above any of the listed action levels or the method quantitation limit
[1]Background metals concentration developed by IT Corporation (1995b)
[2]Oklahoma Corporation Commission (OCC) Category II Clean-up Levels

Qualifier (QFR) Codes
N = Sample is outside of Matrix Spike QC limit
VOCs/SVOCs: B = Analyte is found in the associated blank as well as in the sample
J = Concentration is an estimated value

Table 5-10
Concentrations of Constituents Detected in Groundwater Samples Collected From Temporary Groundwater Probes Area A Service Station

Location	Constituent Concentrations (µg/l)																		
	Fuel Related Constituents										Chlorinated Organic Constituents								
	Benzene	Isopropyl benzene	Ethylbenzene	Naphthalene	N-Propylbenzene	Toluene	1,2,4-Trimethylbenzene	1,3,5-Trimethylbenzene	O-xylene	M-P-xylene	Chloroform	1,2-Dichlorobenzene	1,2 Dichloroethane	Cis-1,2-dichloroethene	Trans-1,2-dichloroethene	Cis-1,3-dichloropropene	Methylene Chloride	Trichloroethene	Vinyl Chloride
OCC Cat. II Standards	50		7,000			10,000			100,000										
CPT-1	2,580	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	211	102	<100	<400	<100	243
CPT-2	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	41.6**	<10	<10
CPT-3	7,830	<500	<500	<500	<500	<500	<500	<500	<500	<500	<500	<500	<500	<500	<500	<500	<2000	<500	<500
CPT-4	<5.0	<5.0	<5.0	<5.0	<5.0	<5.0	<5.0	<5.0	<5.0	<5.0	<5.0	<5.0	20.4	<5.0	<5.0	<5.0	<20.0	<5.0	<5.0
CPT-5	<5.0	<5.0	<5.0	<5.0	<5.0	<5.0	<5.0	<5.0	<5.0	<5.0	<5.0	<5.0	<5.0	<5.0	<5.0	<5.0	<20.0	<5.0	<5.0
CPT-7	< 5.0	< 5.0	< 5.0	< 5.0	< 5.0	< 5.0	< 5.0	< 5.0	< 5.0	< 5.0	< 5.0	< 5.0	< 5.0	< 5.0	< 5.0	5.44	<20.0	24.4	< 5.0
CPT-19	< 5.0	< 5.0	< 5.0	< 5.0	< 5.0	< 5.0	< 5.0	< 5.0	< 5.0	< 5.0	< 5.0	< 5.0	< 5.0	< 5.0	< 5.0	< 5.0	<20.0	< 5.0	< 5.0
CPT-20	< 5.0	< 5.0	< 5.0	< 5.0	< 5.0	< 5.0	< 5.0	< 5.0	< 5.0	< 5.0	< 5.0	< 5.0	< 5.0	< 5.0	< 5.0	< 5.0	<20.0	< 5.0	< 5.0
CPT-22	< 5.0	< 5.0	< 5.0	< 5.0	< 5.0	< 5.0	< 5.0	< 5.0	< 5.0	< 5.0	< 5.0	< 5.0	< 5.0	< 5.0	< 5.0	< 5.0	<20.0	< 5.0	< 5.0
CPT-25	3,620	<250	298	<250	<250	<250	<250	<250	<250	<250	<250	<250	<250	<250	<250	<250	<1000	<250	<250
CPT-27	591	69.9	329	191	99.9	392	670	205	526	1,200	<50	<50	<50	<50	<50	<50	<200	<50	<50
CPT-29	5,680	<250	918	<250	<250	1,640	431	<250	<250	643	<250	<250	1,090	1,260	<250	<250	<1000	<250	<250
CPT-30	< 5.0	< 5.0	< 5.0	< 5.0	< 5.0	< 5.0	< 5.0	< 5.0	< 5.0	< 5.0	< 5.0	< 5.0	< 5.0	< 5.0	< 5.0	< 5.0	<20.0	< 5.0	< 5.0
CPT-31	< 5.0	< 5.0	< 5.0	< 5.0	< 5.0	< 5.0	< 5.0	< 5.0	< 5.0	< 5.0	< 5.0	< 5.0	< 5.0	< 5.0	< 5.0	< 5.0	<20.0	< 5.0	< 5.0
CPT-35	2,020	<100	417	<100	<100	<100	<100	<100	<100	<100	<100	161	575	2,270	<100	<100	<400	<100	276
CPT-38	< 5.0	< 5.0	< 5.0	< 5.0	< 5.0	< 5.0	< 5.0	< 5.0	< 5.0	< 5.0	< 5.0	< 5.0	< 5.0	32.7	< 5.0	< 5.0	<20.0	63.6	< 5.0
CPT-41	< 5.0	< 5.0	< 5.0	< 5.0	< 5.0	< 5.0	< 5.0	< 5.0	< 5.0	< 5.0	< 5.0	< 5.0	< 5.0	< 5.0	< 5.0	< 5.0	<20.0	< 5.0	< 5.0
CPT-42	<5.0	<5.0	11.5	<5.0	<5.0	<5.0	8.03	<5.0	<5.0	12.6	<5.0	<5.0	26.4	<5.0	<5.0	<5.0	<20.0	<5.0	<5.0
CPT-43	< 5.0	< 5.0	< 5.0	< 5.0	< 5.0	< 5.0	< 5.0	< 5.0	< 5.0	< 5.0	< 5.0	< 5.0	< 5.0	< 5.0	< 5.0	< 5.0	<20.0	< 5.0	< 5.0
CPT-44	< 5.0	< 5.0	< 5.0	< 5.0	< 5.0	< 5.0	< 5.0	< 5.0	< 5.0	< 5.0	< 5.0	< 5.0	< 5.0	< 5.0	< 5.0	< 5.0	<20.0	< 5.0	< 5.0

Indicates constituent concentration is above the OCC Category II Cleanup Standard.
Samples analyzed using EPA Method 8260 (USEPA, 1986).

Analytical Results for Groun
1993/1994 and 1994/
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Well ID	Sample Event	1,2,4-Trimethylbenzene	1,2-Dichloroethane	1,2-Dichloropropane	1,3,5-Trimethylbenzene	2-Butanone	4-Isopropyltoluene	Acetone	Benzene	Carbon Tetrachloride	Chlorobenzene
OCC Category II Cleanup Standards									50		
Upper Saturated Zone											
70	94-95	<1 U	<1 U	<1 U	<1 U		<1 U		<1 U	<1 U	<1 U
2-2	93-94		61	<5 U		<100 U		<100 U	330 D	<5 U	1.5 J
2-2	94-95	240	<25 U	<25 U	42		<25 U		1100	<25 U	<25 U
2-3	93-94		<5 U	<5 U		6.7 J		<100 U	3700 D	<5 U	<5 U
2-3	94-95	<1 U	<1 U	<1 U	<1 U		<200 U		2	<1 U	<1 U
2-3	94-95	<200 U	<200 U	<200 U	<200 U		<200 U		920	<200 U	<200 U
2-4	93-94		<250 U	<250 U		<5000 U		<5000 U	6400	<250 U	<250 U
2-50B	93-94		<500 U	<500 U		<10000 U		<10000 U	15000	<500 U	<500 U
2-51B	93-94		180	14 J		<500 U		<500 U	1400 D	<25 U	<25 U
2-51B	94-95	24	<10 U	<10 U	<10 U		1 DJ		530 E	<10 U	<10 U
2-52B	93-94		<5 U	<5 U		<100 U		14 J	<5 U	<5 U	<5 U
2-52B	94-95	<1 U	<1 U	<1 U	<1 U		2		<1 U	<1 U	<1 U
2-145B	94-95	<1 U	<.89 U	<.81 U	<1.1 U	<.96 U	<0.9 U	3.9	<.84 U	<.93 U	<.68 U
2-146B	94-95	<1 U	<.89 U	<.81 U	<1.1 U	<.96 U	<0.9 U	2	<.84 U	<.93 U	<.68 U
2-149B	94-95	<1 U	2.3	<.81 U	<1.1 U	<.96 U	<0.9 U	<1.1 U	<.84 U	<.93 U	<.68 U
2-163B	94-95	<1 U	160	1.5	<1.1 U	<.96 U	<0.9 U	<1.1 U	<.84 U	<.93 U	<.68 U
2-164B	94-95	<1 U	1.3	<.81 U	<1.1 U	<.96 U	<0.9 U	<1.1 U	<.84 U	<.93 U	<.68 U
2-165B	94-95	<1 U	<.89 U	<.81 U	<1.1 U	<.96 U	<0.9 U	<1.1 U	<.84 U	<.93 U	<.68 U
2-166B	94-95	<1 U	<.89 U	<.81 U	<1.1 U	<.96 U	<0.9 U	<1.1 U	<.84 U	<.93 U	<.68 U
2-173B	94-95	<1 U	<.89 U	<.81 U	<1.1 U	<.96 U	<0.9 U	1.8	<.84 U	<.93 U	<.68 U
Lower Saturated Zone											
2-2A	93-94		<5 U	<5 U		<100 U		<100 U	<5 U	24	<5 U
2-2A	94-95	<1 U	0.6 UJ	<1 U	<1 U		<1 U		<1 U	13	<1 U
2-4A	93-94		<5 U	<5 U		<100 U		11 J	<5 U	<5 U	<5 U
2-4A	93-94		<5 U	<5 U		<100 U		<100 U	<5 U	<5 U	<5 U
2-4A	94-95	<1 U	1	<1 U	<1 U		<1 U		<1 U	0.3 J	<1 U
2-51A	93-94		<5 U	<5 U		<100 U		11 J	<5 U	4.2 J	<5 U
2-51A	94-95	<1 U	2	<1 U	<1 U		<1 U		<1 U	6	<1 U
2-52A	93-94		<5 U	<5 U		<100 U		<100 U	<5 U	3.1 J	<5 U
2-52A	94-95	<1 U	0.4 UJ	<1 U	<1 U		<1 U		<1 U	4	<1 U
2-149A	94-95	<1 U	<.89 U	<.81 U	<1.1 U	9.6	<0.9 U	11.4	10.5	<.93 U	<.68 U

Notes:
1. Only detected compounds are provided in this table.
   Groundwater samples were analyzed by EPA Method 8240
2. Qualifer codes are provided after the analytical results. Codes are as follows:
   U-Compound was analyzed for but was not detected.
   J-Estimated Value.
   D-Dilution run. Intial run outside linear range of instrument.
   N-Spiked Sample recovery not within control limits.
3. Shaded results indicate exceedance of the OCC Cleanup Standard.

Table 5-11
Analytical Results for Groundwater Samples - Volatile Organic Compounds
1993/1994 and 1994/1995 Groundwater Sampling Programs
Area A Service Station

Parameters (µg/l)

2-Butanone		4-Isopropyltoluene		Acetone		Benzene		Carbon Tetrachloride		Chlorobenzene		Chloroform		cis-1,2-Dichloroethene		Ethylbenzene		Isopropylbenzene		Methylene Chloride		n-Butylbenzene		Naphthalene		sec-Butylbenzene		tert-Butylbenzene		Tetrachloroethylene
						50										7,000														
		<1	U			<1	U	<1	U	<1	U	<1	U	<1	U	<1	U	<1	U	<4	U	<2	U	<4	U	<1	U	<1	U	<1
0	U			<100	U	330	D	<5	U	1.5	J	<5	U	64		79				<10	U			2.4	J					<5
		<25	U			1100		<25	U	<25	U	<50	U	40		740		27		<100	U	5	UJ	56	J	<25	U	<25	U	<25
	J			<100	U	3700	D	<5	U	<5	U	<5	U	160		6.2				<10	U			4.4	J					<5
		<200	U			2		<1	U	<1	U	<1	U	<1	U	<1	U	<1	U	<4	U	<2	U	<4	U	<1	U	<1	U	1
		<200	U			920		<200	U	<200	U	<200	U	<200	U	<200	U	<200	U	<800	U	<400	U	<800	U	<200	U	<200	U	<200
)0	U			<5000	U	6400		<250	U	<250	U	<250	U	2900		1700				<500	U			470	D					<250
00	U			<10000	U	15000		<500	U	<500	U	<500	U	480	J	2000				<1000	U			410	D					<500
0	U			<500	U	1400	D	<25	U	<25	U	<25	U	<25	U	23	J			<50	U			5.6	J					<25
		1	DJ			530	E	<10	U	<10	U	0.9	UJ	<10	U	18		4	J	2	UJ	<20	U	3	UJ	1	UJ	<10	U	<10
0	U			14	J	<5	U	<5	U	<5	U	<5	U	<5	U	<5	U			<10	U			<10	U					<5
		2				<1	U	<1	U	<1	U	0.4	UJ	<1	U	8		6		<4	U	2	U	8		2		0.3	UJ	<1
5	U	<0.9	U	3.9		<.84	U	<.93	U	<.68	U	<.86	U	<.82	U	<.81	U	<0.7	U	<.85	U	<1.4	U	<.57	U	<1.2	U	<1.1	U	<.66
5	U	<0.9	U	2		<.84	U	<.93	U	<.68	U	<.86	U	<.82	U	<.81	U	<0.7	U	<.85	U	<1.4	U	<.57	U	<1.2	U	<1.1	U	<.66
5	U	<0.9	U	<1.1	U	<.84	U	<.93	U	<.68	U	<.86	U	4.7		<.81	U	<0.7	U	<.85	U	<1.4	U	<.57	U	<1.2	U	<1.1	U	<.66
5	U	<0.9	U	<1.1	U	<.84	U	<.93	U	<.68	U	<.86	U	<.82	U	<.81	U	<0.7	U	<.85	U	<1.4	U	<.57	U	<1.2	U	<1.1	U	<.66
6	U	<0.9	U	<1.1	U	<.84	U	<.93	U	<.68	U	<.86	U	<.82	U	<.81	U	<0.7	U	<.85	U	<1.4	U	<.57	U	<1.2	U	<1.1	U	<.66
6	U	<0.9	U	<1.1	U	<.84	U	<.93	U	<.68	U	<.86	U	<.82	U	<.81	U	<0.7	U	<.85	U	<1.4	U	<.57	U	<1.2	U	<1.1	U	<.66
5	U	<0.9	U	<1.1	U	<.84	U	<.93	U	<.68	U	<.86	U	<.82	U	<.81	U	<0.7	U	<.85	U	<1.4	U	<.57	U	<1.2	U	<1.1	U	<.66
6	U	<0.9	U	1.8		<.84	U	<.93	U	<.68	U	<.86	U	<.82	U	<.81	U	<0.7	U	<.85	U	<1.4	U	<.57	U	<1.2	U	<1.1	U	<.66
0	U			<100	U	<5	U	24		<5	U	<5	U	<5	U	<5	U			<10	U			<10	U					<5
		<1	U			<1	U	13		<1	U	2		0.2	UJ	<1	U	<1	U	<4	U	<2	U	<4	U	<1	U	<1	U	<1
0	U			11	J	<5	U	<5	U	<5	U	<5	U	<5	U	<5	U			<10	U			<10	U					<5
0	U			<100	U	<5	U	<5	U	<5	U	<5	U	<5	U	<5	U			<10	U			<10	U					<5
		<1	U			<1	U	0.3	J	<1	U	1	UJ	0.5	UJ	<1	U	<1	U	<4	U	<2	U	<4	U	<1	U	<1	U	0.1
0	U			11	J	<5	U	4.2	J	<5	U	<5	U	<5	U	<5	U			<10	U			<10	U					<5
		<1	U			<1	U	6		<1	U	1	UJ	2		<1	U	<1	U	<4	U	<2	U	<4	U	<1	U	<1	U	0.2
0	U			<100	U	<5	U	3.1	J	<5	U	<5	U	<5	U	<5	U			<10	U			<10	U					<5
		<1	U			<1	U	4		<1	U	0.8	UJ	0.2	UJ	<1	U	<1	U	<4	U	<2	U	<4	U	<1	U	<1	U	<1
;		<0.9	U	11.4		10.5		<.93	U	<.68	U	<.86	U	<.82	U	1.1		3		<.85	U	<1.4	U	<.57	U	<1.2	U	<1.1	U	<.66

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...ylbenzene	Isopropylbenzene	Methylene Chloride	n-Butylbenzene	Naphthalene	sec-Butylbenzene	tert-Butylbenzene	Tetrachloroethylene	Toluene	trans-1,2-Dichloroethylene	Trichloroethene	Vinyl Chloride	Xylenes (Total)
,000								10,000				100,000
U	<1 U	<4 U	<2 U	<4 U	<1 U	<1 U	<1 U	<1 U	<4 U	<1 U	<1 U	<1 U
		<10 U		2.4 J			<5 U	32	<5 U	210 D	<10 U	81
)	27	<100 U	5 UJ	56 J	<25 U	<25 U	<25 U	130 B	<100 U	130	1 UJ	730
.		<10 U		4.4 J			<5 U	16	<5 U	260 D	39	27
U	<1 U	<4 U	<2 U	<4 U	<1 U	<1 U	1 U	<1 U	<4 U	43	<1 U	<1 U
0 U	<200 U	<800 U	<400 U	<800 U	<200 U	<200 U	<200 U	<200 U	<800 U	480	<200 U	<200 U
0		<500 U		470 D			<250 U	16000 D	<250 U	1100	<500 U	8700
0		<1000 U		410 D			<500 U	24000 D	<500 U	<500 U	<1000 U	9200
J		<50 U		5.6 J			<25 U	17 J	<25 U	15 J	<50 U	51
	4 J	2 UJ	<20 U	3 UJ	1 UJ	<10 U	<10 U	6 BJ	<40 U	<10 U	<10 U	11
U		<10 U		<10 U			<5 U	<5 U	<5 U	<5 U	<10 U	<5 U
	6	<4 U	2 U	8	2	0.3 UJ	<1 U	<1 U	<4 U	0.8 UJ	<1 U	1 U
1 U	<0.7 U	<.85 U	<1.4 U	<.57 U	<1.2 U	<1.1 U	<.66 U	<.87 U	<.85 U	<.92 U	<.9 U	<1.3 U
1 U	<0.7 U	<.85 U	<1.4 U	<.57 U	<1.2 U	<1.1 U	<.66 U	<.87 U	<.85 U	<.92 U	<.9 U	<1.3 U
1 U	<0.7 U	<.85 U	<1.4 U	<.57 U	<1.2 U	<1.1 U	<.66 U	<.87 U	<.85 U	2.6	<.9 U	<1.3 U
1 U	<0.7 U	<.85 U	<1.4 U	<.57 U	<1.2 U	<1.1 U	<.66 U	<.87 U	<.85 U	4.1	<.9 U	<1.3 U
1 U	<0.7 U	<.85 U	<1.4 U	<.57 U	<1.2 U	<1.1 U	<.66 U	<.87 U	<.85 U	<.92 U	<.9 U	<1.3 U
1 U	<0.7 U	<.85 U	<1.4 U	<.57 U	<1.2 U	<1.1 U	<.66 U	<.87 U	<.85 U	<.92 U	<.9 U	<1.3 U
1 U	<0.7 U	<.85 U	<1.4 U	<.57 U	<1.2 U	<1.1 U	<.66 U	<.87 U	<.85 U	10.2	<.9 U	<1.3 U
1 U	<0.7 U	<.85 U	<1.4 U	<.57 U	<1.2 U	<1.1 U	<.66 U	<.87 U	<.85 U	2.4	<.9 U	<1.3 U
U		<10 U		<10 U			<5 U	<5 U	<5 U	6.8	<10 U	<5 U
U	<1 U	<4 U	<2 U	<4 U	<1 U	<1 U	<1 U	<1 U	<4 U	32	<1 U	<1 U
U		<10 U		<10 U			<5 U	<5 U	<5 U	13	<10 U	<5 U
U		<10 U		<10 U			<5 U	<5 U	<5 U	13	<10 U	<5 U
U	<1 U	<4 U	<2 U	<4 U	<1 U	<1 U	0.1 UJ	<1 U	<4 U	38	<1 U	<1 U
U		<10 U		<10 U			<5 U	2.6 J	<5 U	29	<10 U	<5 U
U	<1 U	<4 U	<2 U	<4 U	<1 U	<1 U	0.2 UJ	<1 U	0.1 UJ	130 E	<1 U	<1 U
U		<10 U		<10 U			<5 U	<5 U	<5 U	15	<10 U	<5 U
U	<1 U	<4 U	<2 U	<4 U	<1 U	<1 U	<1 U	<1 U	<4 U	36	<1 U	<1 U
	3	<.85 U	<1.4 U	<.57 U	<1.2 U	<1.1 U	<.66 U	2.5	<.85 U	<.92 U	<.9 U	<1.3 U

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Table 5-12
Analytical Results for Groundwater Samples - Semivolatile Organic Compounds
1993/1994 and 1994/1995 Groundwater Sampling Programs
Area A Service Station

		Parameters (µg/l)												
Well ID	Sample Event	2,4-Dimethylphenol	2-Methylnaphthalene	2-Methylphenol	4-Methylphenol	Acenaphthene	bis(2-Ethylhexyl)Phthalate	Di-n-Butylphthalate	Dibenzofuran	Diethylphthalate	Fluorene	Isophorone	Phenanthrene	Phenol
Upper Saturated Zone														
70	94-95	<10 U	<10 U	<10 U	10	<10 U	18	<10 U	<10 U	<10 U	<10 U	<10 U	<10 U	<10 U
2-2	93-94	<10 U	5.6 J	<10 U	<10 U	<10 U	2.9 J	<10 U	<10 U	<10 U	1 J	<10 U	<10 U	<10 U
2-2	94-95	<10 U	15	<10 U	<10 U	1 UJ	<10 U	<10 U	1 UJ	<20 U	2 J	<10 U	2 J	<10 U
2-3	93-94	<10 U	4.6 J	<10 U	<10 U	<10 U	<10 U	<10 U	<10 U	<10 U	<10 U	<10 U	<10 U	13
2-3	94-95	<10 U	<10 U	<10 U	<10 U	<10 U	<10 U	<10 U	<10 U	<20 U	<10 U	<10 U	<10 U	<10 U
2-3	94-95	<10 U	<10 U	<10 U	<10 U	<10 U	<10 U	<10 U	<10 U	<20 U	<10 U	<10 U	<10 U	<10 U
2-4	93-94	<10 U	280 D	26	26	1.5 J	4.8 J	<10 U	<10 U	<10 U	1.7 J	<10 U	3.4 J	23
2-50B	93-94	21	150	<10 U	30	<10 U	<10 U	<10 U	<10 U	<10 U	1.1 J	<10 U	<10 U	37
2-51B	93-94	<10 U	<10 U	<10 U	<10 U	<10 U	<10 U	<10 U	<10 U	<10 U	<10 U	<10 U	<10 U	4.9 J
2-51B	94-95	<10 U	<10 U	<10 U	<10 U	<10 U	<10 U	<10 U	<10 U	<20 U	<10 U	29	<10 U	<10 U
2-52B	93-94	<10 U	<10 U	<10 U	<10 U	<10 U	<10 U	<10 U	<10 U	<10 U	<10 U	<10 U	<10 U	<10 U
2-52B	94-95	<10 U	<10 U	<10 U	<10 U	<10 U	0.4 UJ	<10 U	<10 U	<20 U	<10 U	<10 U	<10 U	<10 U
2-145B	94-95	<5 U	<5 U	<5 U	<5 U	<5 U	<5 U	<5 U	<5 U	<5 U	<5 U	<5 U	<5 U	<5 U
2-146B	94-95	<5 U	<5 U	<5 U	<5 U	<5 U	<5 U	<5 U	<5 U	<5 U	<5 U	<5 U	<5 U	<5 U
2-149B	94-95	<5 U	<5 U	<5 U	<5 U	<5 U	<5 U	<5 U	<5 U	<5 U	<5 U	<5 U	<5 U	<5 U
2-163B	94-95	<5 U	<5 U	<5 U	<5 U	<5 U	<5 U	<5 U	<5 U	<5 U	<5 U	<5 U	<5 U	<5 U
2-164B	94-95	<5 U	<5 U	<5 U	<5 U	<5 U	<5 U	<5 U	<5 U	<5 U	<5 U	<5 U	<5 U	<5 U
2-165B	94-95	<5 U	<5 U	<5 U	<5 U	<5 U	<5 U	<5 U	<5 U	<5 U	<5 U	<5 U	<5 U	<5 U
2-166B	94-95	<5 U	<5 U	<5 U	<5 U	<5 U	<5 U	<5 U	<5 U	<5 U	<5 U	<5 U	<5 U	<5 U
2-173B	94-95	<5 U	<5 U	<5 U	<5 U	<5 U	<5 U	<5 U	<5 U	<5 U	<5 U	<5 U	<5 U	<5 U
Lower Saturated Zone														
2-2A	93-94	<10 U	<10 U	<10 U	<10 U	<10 U	1.3 J	<10 U	<10 U	<10 U	<10 U	<10 U	<10 U	<10 U
2-2A	94-95	<10 U	<10 U	<10 U	<10 U	<10 U	<10 U	<10 U	<10 U	<20 U	<10 U	<10 U	<10 U	<10 U
2-4A	93-94	<10 U	<10 U	<10 U	<10 U	<10 U	13	<10 U	<10 U	<10 U	<10 U	<10 U	<10 U	<10 U
2-4A	93-94	<10 U	<10 U	<10 U	<10 U	<10 U	<10 U	<10 U	<10 U	<10 U	<10 U	<10 U	<10 U	<10 U
2-4A	94-95	<10 U	<10 U	<10 U	<10 U	<10 U	<10 U	<10 U	<10 U	<20 U	<10 U	<10 U	<10 U	<10 U
2-51A	93-94	<10 U	<10 U	<10 U	<10 U	<10 U	7.1 J	4.3 J	<10 U	2.6 J	<10 U	<10 U	<10 U	<10 U
2-51A	94-95	<10 U	<10 U	<10 U	<10 U	<10 U	<10 U	<10 U	<10 U	<20 U	<10 U	<10 U	<10 U	<10 U
2-52A	93-94	<10 U	<10 U	<10 U	<10 U	<10 U	5.2 J	<10 U	<10 U	<10 U	<10 U	<10 U	<10 U	<10 U
2-52A	94-95	<10 U	<10 U	<10 U	<10 U	<10 U	<10 U	<10 U	<10 U	<20 U	<10 U	<10 U	<10 U	<10 U
2-149A	94-95	<5 U	<5 U	<5 U	<5 U	<5 U	<5 U	<5 U	<5 U	<5 U	<5 U	<5 U	<5 U	<5 U

Notes:
1. Only detected compounds are provided in this table.
   Groundwater samples were analyzed by EPA Method 8270
2. Qualifer codes are provided after the analytical results. Codes are as follows:
   U-Compound was analyzed for but was not detected.
   J-Estimated Value.
   D-Dilution run. Intial run outside linear range of instrument.
   N-Spiked Sample recovery not within control limits.

Table 5-13
Analytical Data for Groundwater Samples - Metals
1993/1994 and 1994/1995 Groundwater Sampling Programs
Area A Service Station

Well ID	Sample Event	Parameters (µg/l) Arsenic	Barium	Chromium VI	Chromium, Total	Copper	Iron	Lead	Mercury	Nickel	Selenium	Silver	Zinc
Upper Saturated Zone													
70	94-95	1.4	10		110			0.5	0.02	23	0.3	1	
2-2	93-94	<1 U	380	<1 U	<1 U	<2.5 U	280	<0.3 U	<0.02 U		<10 U	<1 U	<2 U
2-2	94-95	5	4790		<5 U			<1 U	0.22	18	<2 U	0.45	
2-3	93-94	<1 U	79	<1 U	<1 U	<2.5 U	220	<0.3 U	<0.02 U		<10 U	<1 U	<2 U
2-3	94-95	<0.3 U	80		<1 U			<0.5 U	<0.02 U	<4 U	<0.3 U	<1 U	
2-3	94-95	<0.3 U	90		<1 U			<0.5 U	<0.02 U	<4 U	<0.3 U	<1 U	
2-4	93-94	<1 U	24	<1 U	<1 U	<2.5 U	92	0.81	<0.02 U		<10 U	<1 U	<2 U
2-50B	93-94	1.3	660	<1 U	2	<2.5 U	1700	1.9 N	<0.02 UN		<10 U	<1 U	2.1
2-51B	93-94	<1 U	190	<1 U	2.3	<2.5 U	1200	0.81 N	<0.02 U		<10 U	<1 U	4.2
2-51B	94-95	6.5	3230		90.5			40.5	0.25	131	<2 U	<0.25 U	
2-52B	93-94	<1 U	27	<1 U	2.4	<2.5 U	1500	1.3 N	<0.02 U		<10 U	<1 U	4.9
2-52B	94-95	3	298		19			16.5	0.29	27.5	<2 U	<0.25 U	
2-145B	94-95	<1.55 U	51		<3.5 U			<.25 U	<.2 U	9.6	<2.9 U	<.25 U	
2-146B	94-95	<1.55 U	510		<3.5 U			<.25 U	<.2 U	9.6	<2.9 U	<.25 U	
2-149B	94-95	<1.55 U	360		21			<0.25 U	<0.2 U	8.6	<2.9 U	<0.25 U	
2-163B	94-95	<1.55 U	270		4.4			<.25 U	<.2 U	1.7	<2.9 U	<.25 U	
2-164B	94-95	<1.55 U	380		<3.5 U			<.25 U	<.2 U	22	<2.9 U	<.25 U	
2-165B	94-95	<1.55 U	46		<3.5 U			<.25 U	<.2 U	<.35 U	<2.9 U	<.25 U	
2-166B	94-95	<1.55 U	56		<3.5 U			<.25 U	<.2 U	<.35 U	<2.9 U	<.25 U	
2-173B	94-95	<1.55 U	830		5.4			<.25 U	<.2 U	25	<2.9 U	<.25 U	
Lower Saturated Zone													
2-2A	93-94	<1 U	49 N	<1 U	1.3	4.4	210 N	<0.3 UN	<0.02 UN		10 N	<1 U	9.7
2-2A	94-95	<2	617		30			1 UB	<0.2 U	56	<2 U	<0.25 U	
2-4A	93-94	3.7	<20 UN	1.2	1.7	<2.5 U	96 N	<0.3 UN	<0.02 UN		<10 UN	<1 U	2 U
2-4A	93-94	3.7	<20 UN	<1 U	2.1	<2.5 U	110 N	<0.3 UN	<0.02 UN		<10 UN	<1 U	2.3
2-4A	94-95	6	788		378			2.5	0.24	367	<2 U	0.4 B	
2-51A	93-94	1.8	<20 U	1.9	1.7	<2.5 U	200	<0.3 UN	<0.02 UN		<10 U	<1 U	<2 U
2-51A	94-95	4.5	1320		262			6.5	0.25	169	<2 U	2.5 B	
2-52A	93-94	<1 U	48 N	<1 U	1.9	<2.5 U	54 N	0.32 N	<0.02 UN		10 N	<1 U	<2 U
2-52A	94-95	<2 U	608		6			1 UB	0.27	68	<2 U	<0.25 U	
2-149A	94-95	<1.55 U	120		<3.5 U			<0.25 U	<0.2 U	<0.35 U	<2.9 U	<0.25 U	

Notes:
1. Only detected compounds are provided in this table.
2. Qualifer codes are provided after the analytical results. Codes are as follows:
   - U-Compound was analyzed for but was not detected.
   - J-Estimated Value.
   - D-Dilution run. Intial run outside linear range of instrument.
   - N-Spiked Sample recovery not within control limits.

Table 5-14
Analytical Results for Groundwater Samples -
1993/1994 and 1994/1995 Groundw
Area A Service St

Well ID	Sample Event	Alkalinity, Titrimetric	Calcium	Chemical Oxygen Demand	Chloride by Ion Chrom.	Magnesium	Manganese	Nitrate and Nitrite	Potassium	Silica	Sodium
		Parameters (mg/l)									
OCC Category II Cleanup Standards											
Upper Saturated Zone											
70	94-95										
2-2	93-94	640	140 N		380	63 N	0.5	<0.050 U	<5.0 U	8.7	250 N
2-2	94-95										
2-3	93-94	630	110 N		210	58 N	0.8	<0.050 U	<5.0 U	12	210 N
2-3	94-95										
2-3	94-95										
2-4	93-94	630	130 N		350	64 N	0.38	0.15	<5.0 U	10	260 N
2-50B	93-94	720	110		320	59	1.3	<0.050 U	<5.0 U	24	250
2-51B	93-94	640	240		1000	120	0.74	<0.050 U	<5.0 U	20	390
2-51B	94-95										
2-52B	93-94	300	30	35	12	17	0.38	<0.050 U	<5.0 U	12	89
2-52B	94-95										
2-145B	94-95										
2-146B	94-95										
2-149B	94-95										
2-163B	94-95										
2-164B	94-95										
2-165B	94-95										
2-166B	94-95										
2-173B	94-95										
Lower Saturated Zone											
2-2A	93-94	370	110 N	30	190	50 N	0.08 N	3.9	9.4 N	26	73 N
2-2A	94-95										
2-4A	93-94	190	57 N		170	22 N	0.02 N	2.4	14 N	43	92 N
2-4A	93-94	190	58 N		140	23 N	0.032 N	2.5	15 N	41	95 N
2-4A	94-95										
2-51A	93-94	110	37		140	16	0.04	3	15	36	67
2-51A	94-95										
2-52A	93-94	350	98 N		140	46 N	0.03 N	5.9	6.9 N	20	66 N
2-52A	94-95										
2-149A	94-95										

Notes:
1. Only detected compounds are provided in this table.
2. Qualifer codes are provided after the analytical results. Codes are as follows:
   - U-Compound was analyzed for but was not detected.
   - J-Estimated Value.
   - D-Dilution run. Intial run outside linear range of instrument.
   - N-Spiked Sample recovery not within control limits.

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Table 5-14
ical Results for Groundwater Samples - General Groundwater Parameters
1993/1994 and 1994/1995 Groundwater Sampling Programs
Area A Service Station

Parameters (mg/l)											
Nitrate and Nitrite	Potassium	Silica	Sodium	Sulfate by Ion Chrom.	Total Dissolved Solids	Total Kjeldahl Nitrogen	Total Organic Carbon	Total Phosphorus	Total Suspended Solids	TPH - IR	Turbidity (in NTU)
										10	
					804		2				
<0.050 U	<5.0 U	8.7	250 N	12	1200	0.25 UN	15	<0.1 U	130	1.4	
					1220		13.6				
<0.050 U	<5.0 U	12	210 N	15	1000	0.49 N	11	<0.1 U	43	2.4	
					297		9				
					897		11				
0.15	<5.0 U	10	260 N	110	1300	0.32 N	11	ISSI ND	<20 U	93	
<0.050 U	<5.0 U	24	250	4.6	1400	0.3 N	14	0.14	360	36	
<0.050 U	<5.0 U	20	390	9.5	2600	0.46 N	29	0.27 N	710	2.4	
					1290		18.7				
<0.050 U	<5.0 U	12	89	18	400	0.25 N	1.5	0.29 N	800	1.2	
					376		2.4		376		
					1000		2				19
					780		4				120
					990		<1 U				240
					1700		5				11
					920		1				11
					1000		1				3.7
					900		<1 U				13
					590		2				36
3.9	9.4 N	26	73 N	26	650	<0.25 U	<1.0 U	<0.1 U	58	<1.0 U	
					706		2.2				
2.4	14 N	43	92 N	40	450	<0.25 U	<1.0 U	<0.1 U	96	<1.0 U	
2.5	15 N	41	95 N	43	460	<0.25 U	<1.0 U	<0.1 U	93	<1.0 U	
					631		2.1				
3	15	36	67	29	490	0.7 N	2.7	0.32	110	<0.9 U	
					653		3				
5.9	6.9 N	20	66 N	38	600	<0.25 U	<1.0 U	<0.1 U	52	<0.9 U	
					596		1.9				
					930		5				10

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ameters

)	Total Organic Carbon		Total Phosphorus		Total Suspended Solids		TPH - IR		Turbidity (in NTU)
							10		
	2								
UN	15		<0.1	U	130		1.4		
	13.6								
N	11		<0.1	U	43		2.4		
	9								
	11								
N	11		ISSI	ND	<20	U	93		
N	14		0.14		360		36		
N	29		0.27	N	710		2.4		
	18.7								
N	1.5		0.29	N	800		1.2		
	2.4				376				
	2								19
	4								120
	<1	U							240
	5								11
	1								11
	1								3.7
	<1	U							13
	2								36
U	<1.0	U	<0.1	U	58		<1.0	U	
	2.2								
U	<1.0	U	<0.1	U	96		<1.0	U	
U	<1.0	U	<0.1	U	93		<1.0	U	
	2.1								
N	2.7		0.32		110		<0.9	U	
	3								
U	<1.0	U	<0.1	U	52		<0.9	U	
	1.9								
	5								10

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APPENDIX D

TINKER AFB WELL INSTALLATION STANDARDS

12.0 WELL INSTALLATION STANDARDS

12.1 Borehole Drilling

12.1.1 General: Each borehole shall be drilled in accordance with these procedures and applicable EPA and ASTM procedures. Drilling operations and well installation shall be supervised by an experienced and degreed geologist/hydrogeologist.

12.1.2 Location of Boreholes: The approximate location and depth of the boreholes and the number of boreholes will be specified in the Delivery Order. The exact location, depth, and number of boreholes for the study shall be determined in the field by the contractor in consultation with the authorized Environmental Management Directorate representative.

12.1.3 Drilling Fluid Additives: Bentonite is the only drilling fluid additive allowed. No organic additives shall be used. Exception is usually made for some high yield bentonites to which the manufacturer has added a small quantity of polymer additive. The use of any bentonite must be approved by the Contracting Officer prior to the arrival on-site of the drilling equipment (rigs). This includes bentonites (powders, pellets, etc.) intended for drilling mud, grout seals, etc. The following data shall be submitted in writing through the Environmental Management Directorate (OC-ALC/EM) to the Contracting Officer as part of the approval request:

a. Brand Name(s)
b. Manufacturer(s)
c. Manufacturer's address(es) and telephone number(s)
d. Product description(s) from package label(s) and manufacturer's brochure(s)
e. Intended use(s) for this product
f. Name and phone number of approving State or Federal EPA representative. Allow six working days from the time of receipt by EM for Contracting Officer approval.

12.2 Water Sources

12.2.1 On-site Requirements: The source(s) of any water to be used in drilling, grouting, sealing, purging, well installation, or equipment washing shall be approved by the Contracting Officer or authorized representative prior to arrival of the drilling equipment on-site. Water source(s) shall meet the following requirements:

a. A deep aquifer origin (greater than 200 feet below ground surface)
b. Upgradient of potential contaminant sources
c. Free of survey related contaminants by virtue of pre-testing

d. Water shall not be treated or filtered
e. 24-hours-a-day and 7-days-a-week access
f. Water flow sufficient to allow the filling of a 500-gallon tank in less than 20 minutes
g. The use of only one designated tap for access
h. Surface water bodies shall not be used

12.2.2 Off-site Sources: If a suitable source exists on-site, the contractor shall use that source. If no on-site water is available, the contractor shall locate a potential source(s) and submit the following data in writing through the Environmental Management Directorate (EM) to the Contracting Officer for approval prior to the arrival of any drilling equipment on-site:

a. Owner/Address/Telephone Number
b. Location of Tap/Address
c. Type of Source (well, to include static water level, date measured, well depth, and aquifer description, pond, river, etc).
d. Type of treatment prior to tap (chlorination, fluoridation, softening, etc).
e. Time of Access (24-hours per day, 5-days per week, etc).
f. Cost per gallon
g. Results and dates of all available chemical analysis over past two years. Allow six working days from the time of receipt by EM for Contracting Officer approval. The contractor has the responsibility to procure, transport, and store the water required for project needs in a manner to avoid the chemical degradation of the water once obtained.

12.2.3 Tanks: Portable recirculation tanks are required for mud/water rotary formations and similar requirements. The use of dug sumps/pits (lined or unlined) is expressly prohibited.

12.3 Boring/Well Abandonment

12.3.1 The abandonment of any borings or wells shall be approved by the Contracting Officer or authorized representative prior to any casing removal, sealing, or backfilling. The Contractor shall provide the Contracting Officer or authorized representative with the following data:

a. Designation of well/bore in question
b. Current status (depth, contents of hole, stratigraphy, water level, etc)
c. Reason for abandonment
d. Recommendation

A written follow-up request shall be made by the contractor within five working days of the telephone request. This document shall be forwarded through EM for Contracting Officer approval and

contain the same data as above.

12.3.2 Sealing of Abandoned Wells: Once approved, the boring or well to be abandoned shall be sealed by grouting from the bottom of the boring/well to ground surface (i.e., to the maximum depth drilled/bottom of well screen) and grout pumped through this pipe until undiluted grout flows from the boring/well at ground surface. Any open or ungrouted portion of the annular space between the well casing and borehole shall be grouted in the same manner. After grout placement, the drill casing/augers may be removed. When conditions permit, the grout placement and casing removal shall be done incrementally so as to constantly maintain 10 feet of grout within the casing yet to be removed from the ground.

12.3.3 Grout Settlement: After 24 hours, the contractor shall check the abandoned site for grout settlement. That day, any settlement depression shall be filled with grout and rechecked 24 hours later. This process shall be repeated until firm grout remains at ground surface without any depressions present.

12.3.4 Well Screen and Casing Removal: Normal abandonment of monitoring wells shall include removing casing riser and well screen as well as filter pack, grout, and bentonite seal materials. This may require a partial or total hole drilling prior to sealing the well site. This determination will be made by the authorized EM representative for Contracting Officer approval when the request for well abandonment is made by the contractor. Alternate well abandonment procedures may be used with the approval of the Contracting Officer or authorized representative.

12.3.5 Well/Boring Record: For each abandoned boring/well, an entry shall be prepared in the Boring/Well Record (Data Item # A051) which includes the following information:

a. Boring/well designation.
b. Location with respect to the replacement boring or well (e.g., 20 feet north and 20 feet west of well 14).
c. Open depth prior to grouting and depth to which grout pipe placed. This includes the depth of open hole, open depth to the bottom of the well, and the open depth in the well-borehole annulus.
d. Casing left in hole by depth, composition, and size.
e. Copy of the boring log.
f. Diagram of abandoned well
g. Drilled and sampled depth prior to decision to abandon site.
h. Items left in hole by depth, description, and composition.
i. Description and total quantity of grout used initially.
j. Description and daily quantities of grout used to compensate for settlement.
k. Dates of grouting.

l. Water or mud level (specify) prior to grouting and date measured.
m. Remaining casing above ground surface: Height above ground, size, and composition.

Note: All depths/heights shall be reported from ground surface. The original record shall be submitted to the Contracting Officer three days after abandonment is completed.

12.3.6 Replacement Borings/Wells: Replacement wells/borings shall be offset at least 20 feet from any abandoned site in a up or cross-gradient groundwater direction. Site specific conditions may necessitate variation to this placement, but any such placement shall be approved by the Contracting Officer.

12.4 Tracers, Dyes, and Other Substances

Tracers, dyes, or other substances shall not be used or otherwise introduced into borings, wells, grout, backfill, ground, or surface water unless specifically required by contract.

12.5 Geologist Requirements

A geologist representing the contractor shall be present and responsible at each operating drill rig for the logging of samples, monitoring of drilling operations, recording of water losses/gains and groundwater data, preparing the boring logs and well diagrams, and recording the well installation procedures of that rig (Data Item # A051). Each geologist shall be responsible for only one operating rig. Each geologist also shall have on-site, as a minimum, their own copy of the approved Work Plan and Safety Plan (approved after issuance of delivery order). Each geologist also shall have on-site their own 10X hand lens and weighted steel or iron tape(s) long enough to measure the deepest well within the delivery order and heavy enough to reach that depth and small enough to readily fit within the annulus between the well and drill casing. Each geologist shall also have on-site a water level measuring device (preferable electrical) and the necessary material to decontaminate the water level measuring device.

12.6 Soil Samples

12.6.1 General: Unless otherwise specified in the delivery order, intact soil samples to determine physical descriptions, retention, and physical analyses shall be taken and retained every five feet or at each major change of material, whichever occurs first, for two borings only. These samples shall be obtained with driven (e.g. split spoon), pushed (e.g. thin well), or rotary (e.g. Denison) type samplers. Auger flight or wash samples will not satisfy this requirement.

12.6.2 Soil Containers: Representative soil samples from

each sampler shall be placed in half pint or one pint glass jars with airtight, screw type lids (canning jars). These jars shall be stored in individual compartments in cardboard boxes. A single box shall not contain more than 24 one-pint jars or 48 half-pint jars. For thin wall (shelby) samples, a sample shall be retained from each tube as described above. The remaining portion may be wasted or sealed in the tube, as per testing requirement. Minimum information on each sample container shall include the boring and sample number. No geotechnical data shall appear on the container that is not specified on the boring log. Jars and tubes shall be kept from freezing.

12.7 Drilling Requirements

12.7.1 General: The contractor shall be responsible for securing and complying with any and all boring or well drilling permits required by state or local authorities and for determining and complying with any and all state and local regulations with regard to the submission of well logs, samples, etc. Submission of these items to the state or local authorities shall be coordinated through EM.

12.7.2 Safety and Utility Requirements: The contractor shall be responsible for determining and complying with any and all (to include project site) regulations, requirements, and permits with regard to drilling safety and underground utility detection. The contractor shall include a discussion of its actions with regard to these items in his Safety Plan.

12.7.3 Lubrication Requirements: Only petroleum jelly, teflon tape, lithium grease, or vegetable-based lubricants shall be used on the threads of downhole drilling equipment. Additives containing lead or copper shall not be used.

12.7.4 Surface Runoff: Surface runoff; e.g., precipitation, wasted or spilled drilling fluid, and miscellaneous spills and leaks, shall not enter any boring or well either during or after drilling/well construction. To help preclude this, the use of starter casing, recirculation tanks, berms about the borehole, and surficial bentonite packs, as appropriate, is suggested.

12.7.5 Antifreeze: If antifreeze is added to any pump, hose, etc., in an area in contact with the drilling fluid, then the antifreeze shall be completely purged from the equipment prior to the equipment's use in drilling, mud mixing, or any other part of the overall drilling operation. Only antifreeze without rust inhibitors and/or sealants shall be used. The contractor shall note on the boring log the dates, reasons, quantities, and brand names of antifreeze used.

12.7.6 Cleaning of Equipment: The steam cleaning of all

drilling equipment (to include rigs, water tanks (inside and out), augers, drill casing rods, samplers, tools, recirculation tanks, etc.) shall be done prior to project site arrival followed by washing with approved water between different boring/well sites. Prior to use on-site, all casings, augers, recirculation and water tanks, etc., shall be devoid both inside and out of any asphaltic, bituminous, or other encrusting or coating materials, grease, grout, soil, etc. Paint, applied by the equipment manufacturer, need not be removed from drilling equipment.

12.8 Drilling Methods

12.8.1 Hazardous Conditions and Soil Cuttings: The contractor shall monitor all exploratory well drilling and borehole operations with an OVA or comparable instrument to identify potential generation of hazardous and/or toxic materials. In addition, the contractor shall monitor drill cuttings for discoloration and odor. During drilling operations, if soil cuttings are suspected to be hazardous (based on OVA measurement, odors, or discoloration), the contractor shall place them in proper containers and test them using TCLP, ignitibility, or organics (EPA Method 624) as appropriate. The contractor shall handle, transport, store, treat and/or dispose of all waste, both nonhazardous and hazardous (Ref. Section 3.6) Drums shall be labeled in accordance with the Tinker AFB hazardous waste identification system (Tinker AFB Reg. 19-5). Results of this monitoring shall be included in Well/Bore Record. All cuttings on private property that are not hazardous shall be adequately collected, removed, and properly disposed.

12.8.2 Laboratory Soil Tests: Laboratory soil tests shall be taken of each formation or stratum as determined by the on-site geologist at a maximum of two bore holes or for a minimum of 20 stratums. Laboratory testing for soil samples shall as a minimum consist of moisture content and gradation analyses for 1-1/2 inch to #200 sieve; less than #200 sieve requires a hydrometer analysis, Atterberg Limits, and organic content.

12.8.3 Drilling Techniques: Wet rotary, hollow stem auger, and air rotary are acceptable drilling techniques. The technique to be used will vary with site/project requirements. Where split-spoon and shelby tube samples are required, the hollow stem auger shall be used. Samples shall be collected, containerized, described and logged at five foot intervals or at stratum changes. If saturated zones are encountered and the hole is to go through it, then advancing casing techniques shall be used by the contractor. Alternate drilling techniques may be used with the approval of the Contracting Officer or authorized representative.

12.8.4 Reserved

12.8.5 Air Compressor Oil: The contractor shall specify

the type of air compressor and lubricating oil used and retain a pint sample of each type and lot of oil for characterizations, in the event of future problems.

12.8.6 Air Line Filter: The contractor shall have a air line oil filter on the air line and shall change the filter per manufacturer's recommendation during operations with a log kept of this maintenance in the Well/Bore Record (Data Item #A051). More frequent changes shall be made if oil is visibly detected in the filtered air.

12.8.7 Additives: The use of any additives except for water and those approved by the Contracting Officer or authorized representative for dust control and cutting removal shall be prohibited. See Section 12.2.

12.8.8 Downhole Hammer/Bit: The contractor shall refrain from using any downhole hammer/bit. The contractor shall preclude residual groundwater sample contamination caused by the lubrication of the downhole equipment.

12.8.9 Air Usage: The contractor shall fully describe air usage in the Well/Bore Record (Data Item #A051) to include equipment description(s), manufacturer(s), model(s), air pressure used, frequency of oil filter change, and evaluations of the system performance, both design and actual.

12.9 Water Levels

12.9.1 Static Water Measurements: For contouring and reporting purposes (Well/Bore Record, Data Item # A051), at least one complete set of static water level measurements shall be made by the contractor over a single, consecutive 10-hour period for all wells considered in the project. Static levels in borings not converted to wells shall be included if practical and technically appropriate.

12.9.2 Other Measurements: The contractor shall determine and report the relative elevation difference to within +/- 0.5 foot, between any stream lake, or open water body, and wells located within 300 feet of these features. The contractor shall use the data for the refinement of the groundwater contours in the vicinity of the surficial water bodies and wells (Well/Bore Record, Data Item # A051).

12.9.3 Restoration of Work Area: All work areas around the well and/or boring sites installed as part of this contract shall be restored to a physical condition equivalent to that of pre-installation. This includes cutting removal and/or spreading and rut removal.

12.10 Geophysical Logs

12.10.1 Geophysical Logs: All boreholes drilled to 50 feet or deeper shall have calibrated geophysical logs run in each section of the open borehole unless otherwise authorized by the Contracting Officer or authorized representative. At a minimum, natural gamma ray, spontaneous potential, and caliper logs shall be run (Data Item #A079). The Geophysical Log shall be incorporated as part of the Well/Boring Record (Data Item #A051).

12.10.2 Submittal: Each original boring log shall be submitted directly from the field to the Contracting Officer or authorized EM representative within 3 working days after the boring is completed. In those cases where a monitoring well or other instrument is to be inserted into the boring, both the log for the boring and the installation diagram shall be submitted within 3 working days after the instrument is installed. Only the original boring log (and diagram) shall be submitted from the field to fulfill the above requirement. Carbon, typed or reproduced copies will not suffice.

12.10.3 Composing of Field Logs: The contractor shall compose logs directly in the field without transcribing from a field book or other document. This technique reduces off-site work hours for the geologist, lessens the chance for errors of manual copying, and allows the completed document to be field-reviewed closer to the time of drilling.

12.10.4 The following information shall be routinely entered on the boring log or attached to the log:

a. Depths/heights shall be recorded in feet and fractions thereof (tenths or inches).
b. Soil classifications shall be in accordance with the Unified Soil Classification System (equivalent to ASTM D 2487-85).
c. Soil classifications shall be prepared in the field at the time of sampling by the geologist and are subject to change based upon laboratory tests and/or subsequent review. Any such changes shall be incorporated in the project report(s). The reports and boring logs shall be corrected by the contractor. A separate addendum to the logs for these changes shall be included with the geotechnical or final report submission, as appropriate.

12.10.5 Soil Sample Descriptions: Each soil sample taken shall be fully described in the log. The descriptions of intact samples shall include the following parameters:

Parameter	Example
Classification	Sandy Clay

Unified Soil Classification Symbol	CL
Secondary Components & Estimated Percentages Sand:	25% (Fine sand 5% Coarse sand, 20 %)
Color (using Munsell Coil or Geological Society of America ((GSA) Rock Color Chart), give both narrative and numerical description. Munsell and note which chart used.	Gray: 7.5 YR 5/0 Munsell
Plasticity	Low Plasticity
Consistency (cohesive soil)	Stiff
Density (non-cohesive soil)	Loose
Moisture Content, do not express as a percentage unless a lab value	Dry, moist, wet, etc.
Texture/Fabric/Bedding & Orientation	No apparent bedding; numerous vertical, iron-stained tight fractures
Depositional Environment & Formation,	Glacial till, Twin Cities Formation

12.10.6 Secondary Soil Constituents: In the field, visual numeric estimates shall be made of secondary soil constituents; e.g. "silty sand with 20 percent fines" or "sandy gravel with 40 percent sand". If such terms as "trace", some , several , etc., are used, their quantitative meaning is to be defined on each log or within a general legend.

12.10.7 Disturbed Samples: When used to supplement other sampling techniques, disturbed samples; e.g., wash samples, cutting, and auger flight samples shall be described in terms of the appropriate soil/rock parameters to the extend practical. "Classification" shall be minimally described for these samples, along with a description of drill action and water losses/gains for the corresponding depth.

12.10.8 Bentonite Use: The contractor shall record the brand name and amount of any bentonite used for each boring along with the reason for its use and the starting depth.

12.10.9 Drilling Equipment: The drilling equipment used shall be generally described on the log or in a general legend in the Well/Bore Record (Data Item # A051). Record such information as rod size, bit type, pump type, rig manufacturer and model. The log shall record the drilling sequence; e.g.:

a. Opened hole with 8" auger to 9'.
b. Set 8" casing to 10'.
c. Cleaned out and advanced hole with 8" roller bit to 15' (clean water, no water loss).
d. Drove standard sampler to 16.5'.
e. Advanced with 8" roller bit to 30', 15 gallon water loss.
f. Drove standard sampler to 31.5'.
g. Hole heaved to 20'.
h. Mixed 25 pounds of ABC bentonite in 100 gallons of water for hole stabilization and advanced with 8" roller bit to 45', etc.
i. The contractor shall record all special problems and their resolution on the log; e.g., hole squeezing, recurring problems at a particular depth, grout in wells, excessive grout takes, drilling fluid losses, unrecovered tools in hole, lost casings and screens, etc.
j. The dates for the start and completion of borings shall be recorded by the contractor on the log along with notation by depth for drill crew shifts and individual days.
k. Each sequential boundary between the various soils and individual technologies shall be noted by the contractor on the log by depth. When depths are estimated, the estimated range shall be noted along with the boundary.
l. The depth of the first encountered free water shall be indicated along with the method of determination; e.g., "37.6' from direct measurement after drilling to 40.0 feet"; or "40.1' from the direct measurement in 60' hole when boring left overnight, hole dry at end of previous shift:; or "25.0' encountered water to partially stabilize (5 to 10 minutes) and record this secondary level and time between measurements before proceeding. Also, describe any other distinct water level(s) found below the first.
m. The estimated interval by depth for each sample taken, classified, and/or retained shall be noted on the log. For each driven (split spoon), thin wall (shelby), and cored sample, record the length of sampled interval and length of sample recovery. Record the sampler type and size (diameter and length).
n. Record the blow counts, hammer weight, and length of hammer fall for driven samplers. For thin wall samplers, indicate whether the sampler was pushed or

driven.

o. When drilling fluid is used, quantitatively record fluid losses and/or spillage and intentional wasting (e.g., recirculation tank cleaning) to more accurately estimate the amount of fluid lost to the subsurface environment.

p. Record the pumping pressures typically used during oil rotary drilling operations.

q. Note the total depth of drilling sampling, whichever is deeper, on the log.

12.11 Well Installation

12.11.1 Beginning Well Installation: The installation of each type of well shall begin within 12 consecutive hours of boring completion for uncased or partially cased holes. Installation shall begin within 48 consecutive hours for fully cased holes. Once installation has begun, no breaks in the installation process shall be made until the well has been grouted end drill casing removed. Exceptions shall be requested in writing by the contractor through EM for Contracting Officer approval prior to drilling. Data to include in this request are:

a. Well(s) in question.
b. Circumstances.
c. Recommendation and alternatives.

Note: Allow three working days from the time of receipt by EM for Contracting Officer approval.

12.11.2 Delays: In cases of unscheduled delays such as personal injury, equipment breakdowns, sudden inclement weather, or scheduled delays such as borehole geophysics, no advance approval of delayed well installation is needed. In those cases, installation shall be resumed as soon as practical. In cases where a partially cased hole into bedrock is to be somewhat developed prior to well insertion, the well installation shall begin within 12 consecutive hours after this initial development.

12.11.3 Interruptions: Once begun, well installation shall not be interrupted due to the end of the contractor's/driller's work shift, darkness, weekend, or holiday. The contractor shall ensure that all materials for a given well are available and on-site prior to drilling that well.

12.12 Granular Backfill

12.12.1 Approval of Backfill: The contractor shall determine the granular backfill and screen slot size. All granular backfill shall be approved by the Contracting Officer prior to drilling. A one-pint representative sample of each proposed granular backfill (sand/gravel or filter pack) accompanied by the data below is required for Contracting Officer approval prior to

drilling. Each sample shall be described, in writing, in terms of:

a. Lithology.
b. Grain size distribution.
c. Trade name, if any.
d. Source, both company from whom purchased and location of pit or quarry of origin.
e. Processing method; e.g., pit run, screened and unwashed, screened and washed with water from well/river/pond, etc.
f. Slot size of intended screen.

Allow eight working hours for Contracting Officer's approval once all of the above data is received by EM.

12.12.2 Backfill Characteristics: Granular backfill shall be chemically and texturally clean (as seen through a 10X hand lens), inert, siliceous, and of appropriate size for the well screen and host environment.

12.12.3 Backfill level: Granular backfill (sandpack/filter pack) shall extend a maximum of 2 feet above the screen unless otherwise specified in the Statement of Work. In wells constructed deeper than 200 feet, up to 5 feet of sandpack may be required to account for possible compression of the filterpack material. The filterpack shall not penetrate any confining layer either above or below the screen interval without the approval of the Contracting Officer or authorized representative.

12.13 Protective Casing

12.13.1 General: The contractor shall install the protective casing around each monitoring well within 24 hours of initial grout placement around that well unless flush mounted. Requests for exceptions on usage, design, and timing of placement will be considered on a case-by-case basis by the Contracting Officer. Requests in writing shall be made through the authorized EM representative prior to drilling. Include in the request the well(s) involved, reason for request, cost savings, recommendation, and alternatives. Allow six working days for Contracting Officer's approval after the request is received by EM.

12.13.2 The contractor shall include the minimum elements of protection design listed below:

a. A black iron/steel protective casing with hinged locking cover unless wells are flush mounted. The protective casing shall be a minimum length of 5 feet, extending about 2.5 feet above ground surface with the base set in grout.
b. A 8" protector pipe for 5" wells.

c. A 6" protector pipe for 4" wells.
d. A 5" protector pipe for 3" wells.
e. A 4" protector pipe for 2" wells.
f. A highted cover or loose fitting telescoping cap to keep precipitation and runoff out of the casing.
g. All protective casing covers/caps secured to the casing by means of a padlock from the date of protective casing installation.
h. All padlocks to be placed on monitoring wells shall match locks on existing wells and be keyed the same.
i. No more than 3.6" from the top of protective casing to the top of well casing.
j. All above ground well completions shall be painted black with a white cover. White well numbers shall be painted on the black exterior of the protective casing in large enough letters/numbers to be identified from a distance of 50 feet. Painting shall be accomplished with a paint brush (no aerosol cans), and must be dry prior to development.
k. The well designation shall be permanently stamped on the top of the hinged locking cover and on top of each well cap for the above ground well completions. For flush mount completions, the well designation shall be stamped on the bolt down cover and on the top of the well cap.
l. The four-foot radial placement of four guard posts: Each post shall be 6" diameter steel and placed about three feet below ground, rising three feet minimally above ground. Guard posts shall be painted yellow. Installation required prior to sampling.
m. The placement of an internal mortar collar within the well-protective casing annulus from ground surface to 1/2-foot above ground surface with a 1/4" diameter hole (drainage port) in the protective casing centered 1/8" above this level. The mortar mix shall be (by weight) one part cement to two parts sand (the granular backfill used about the well screen), with minimal water for placement. Placement required at least 48 consecutive hours prior to well development.
n. The application of an 8 inch thick, 3-feet by 3 feet concrete pad sloped away from the monitoring well casing to prevent water from collecting around and entering into the well. The pads shall be contoured so that the edge of the pad is flush with the surrounding surface elevation. Completion of the pad is required prior to development.
o. Unique specifications for flood protection, if applicable, are covered in the Statement of Work.
p. Flush surface completions shall have bolt down covers with water proof seals and a

locking mechanism on the well cap.

12.14 Grout and Placement

12.14.1 General: Grout, when used in monitoring well construction or well abandonment, shall be composed by weight of 10 parts cement (portland cement, any of types I to V) to 1/2 part bentonite with a maximum of 10 gallons of approved water per 94-pound bag of cement. Neither additives nor borehole cuttings shall be mixed with the grout. Bentonite shall be added after the required amount of cement is mixed with water. All grout materials shall be combined in an above-ground rigid container and mixed on-site to produce a thick, lump-free mixture.

12.14.2 Grouting Monitoring Wells (bentonite seal): Grout shall be placed in the monitoring wells as follows when a bentonite seal is used:

a. Prior to exposing any portion of the borehole above the seal by the removal of any drill casing (to include hollow-stem augers), the annulus between the well casing shall be filled with grout.
b. The grout shall be placed from within a tremie pipe, located just over the top of the seal.
c. The grout shall be pumped through this pipe to the bottom of the open annulus until undiluted grout flows from the annulus at ground surface, forming a continuous grout column from the seal to ground surface.
d. The drill casing shall then be removed and more grout immediately added to compensate for settlement.
e. If drill casing (to include hollow-stem auger) was not used, the contractor shall proceed with grouting to ground surface in one, continuous operation.
f. After 24 hours, the contractor shall check the site for grout settlement and that day add more grout to fill any settlement depression.
g. The process shall be repeated until firm grout remains at ground surface.
h. Incremental quantities of grout added in this manner shall be recorded as added to the Well/Bore Record.

12.14.3 RESERVED

12.15 Bentonite Seals

12.15.1 General: Bentonite seals shall be composed of commercially available pellets. Pellet seals shall be a minimum of five feet thick as measured immediately after placement, without allowance for swelling.

12.15.2 Slurry Seals: The contractor shall only use slurry

seals as a last resort, as when the seal location is too far below water to allow for pellet or containerized-bentonite placement within a narrow well-borehole annulus. Slurry seals shall have a thick, batter-like consistency with a placement thickness of five feet maximum.

12.15.3 Bedrock: In wells designed to monitor bedrock, the bentonite seal shall be located at least three feet below the top of firm bedrock, as may be determined by drilling refusal. Firm bedrock references to that portion of solid or relatively solid, moderately to unweathered bedrock where the frequency of loose and fractured rock is markedly less than in the bentonite seal and the top of the highly weathered bedrock shall be filled with grout.

12.15.4 Purging Borehole: When a borehole, made with or without the use of drilling fluid, retains an excessively thick, particulate laden fluid which would preclude or practically hinder contractual well installation, the bore may be purged with approved water. This purging is intended to remove or dilute the thick fluid and thus allow the proper placement of well, granular backfill and seal. Fluid losses in this operation shall be initially recorded on the well diagram or Well/Boring Record.

12.15.5 Well Centralizers: Well centralizers, when used, shall be of stainless steel or polyvinyl chloride (PVC) and shall be attached to the riser with stainless steel clamps. No glue of any kind shall be used. Centralizers shall not be attached to the well screen or to that part of the well casing exposed to the granular backfill.

12.15.6 Caps: The tops of all well casings shall be fitted with undersized PVC plugs or oversized PVC caps both of which shall be easily removed by hand.

12.16 Well Screens, Casings, and Fittings

12.16.1 Materials: PVC, fiberglass, and/or stainless steel shall be used for well casings and fittings.

12.16.2 Well Screens: All well screens shall be stainless steel, commercially fabricated, slotted or continuously wound, and have an inside diameter equal to or greater than the well casing. Stainless steel screens may be used with PVC casing. No fitting (coupling) shall restrict the inside diameter of the joined casing and/or screen. All screens, casings and fittings shall be new. Schedule 40 PVC pipe shall be used for shallow upper zone wells and schedule 80 PVC pipe for deeper wells (over 100 feet).

12.16.3 Foreign Matter: The contractor shall ensure that all well screens and well casings are free of foreign matter (e.g., adhesive tape, labels, soil, grease, etc) and washed with approved water prior to use. Washed screens and casings shall be stored in

plastic sheeting or kept on racks prior to insertion. The contractor shall run a dummy pump through all screen and casing to ensure access by pumps and bailers.

12.16.4 Screen Placement: The contractor shall place well screens no more than three feet above the bottom of the drilled bore hole; holes that are deeper than screen location shall be backfilled with bentonite slurry.

12.16.5 Caps: All screen bottoms shall be securely fitted with a cap or plug of the same composition as the screen. This cap/plug shall be within 0.5 foot of the open portion of the screen.

12.16.6 Silt Traps: Installation of a silt trap (sump) may be necessary and depends on site/project requirements. Sumps shall extend a maximum of 3 feet below the bottom of the screen and shall not penetrate the lower confining layer.

12.16.7 Joints: Joints within and between the casing and screen shall be threaded with matching threads. All joints shall be flush inside. Non-factory, heat-welded joints shall not be used. The addition of "O" ring seals will depend on site specific requirements and shall be approved by the Contracting Officer or designated representative.

12.17 Well Construction Diagrams

12.17.1 General: Each installed well shall be depicted in a well diagram prepared by the contractor. This diagram shall be attached to the bore log for that installation and shall graphically denote, by depth from ground surface (unless otherwise specified), the following:

I. General:

a. The bottom of the boring (that part of the boring most deeply penetrated by drilling and/or sampling).
b. Screen location(s).
c. Granular backfill.
d. Seals.
e. Grout.
f. Cave-in.
g. Centralizers.
h. Height of riser without cap/plug (above ground surface).

II. Protective Casing Details:

a. Height of protective casing without cap/cover (above ground surface).
b. Base of protective casing.

c. Drainage port location and size.
d. Internal mortar collar location.
e. Gravel blanket height and extent.
f. Wood/steel post configuration.

III. Describe on the diagram or on an attachment thereto:

a. The actual quantity and composition of the grout, seals, and granular backfill used for each well.
b. The screen slot size (in inches), slot configuration, total open area per foot of screen, outside diameter, nominal inside diameter, schedule/thickness, composition, and manufacturer.
c. The coupling/joint design and composition.
d. Centralizer design and composition.
e. Protective casing composition and nominal inside diameter.
f. The use of solvents, glues, and cleaners to include manufacturer and type (specification).
g. Dates for the start and completion of well installation.

12.17.2 Submittal: The contractor shall submit each diagram (attached to the boring log) to the authorized EM representative within three working days after well installation. Do not delay this submission until all elements of well protection have been installed. The contractor shall submit a supplemental diagram for all protection elements to the authorized EM representative within three working days after all elements of well protection are installed. Only the original well diagram and log shall be submitted to fulfill the above requirement. Carbon, typed, or reproduced copies shall not suffice. A legible copy of the well diagram may be used as a base for the supplemental protection diagram.

12.18 Well Development

12.18.1 General: After installation, wells shall be properly developed by the contractor. Development methods for all wells shall be approved by the Contracting Officer or authorized representative. Natural hydraulic conductivity of the formation shall be restored and all foreign sediment removed by the contractor to ensure turbid-free groundwater samples. The contractor shall provide references that affirm his development procedures. Correct development procedures can expedite sample filtration and can have affect on samples being representative of water in the formation being monitored. Development shall be accomplished with a pump and may be supplemented with a bottom discharge/filling bailer (for sediment removal). A bottom discharge/filling bailer may be used in lieu of a pump in 2-inch wells.

12.18.2 Schedule: The development of monitoring wells shall be performed as soon as practical after well installation, but no sooner than 48 consecutive hours after internal mortar collar placement. The record of well development shall be submitted to the Contracting Officer within three working days after development.

12.18.3 Development shall proceed in the manner described and continue until the following conditions are met:

a. The well water is clear to the unaided eye.
b. The sediment thickness remaining within the well is less than 5% of the screen length.
c. In addition to minimally removing 5 times the standing water volume in the well (to include the well screen and casing plus saturated annulus, assuming 30% porosity), the following conditions also apply:

1. For those wells where the boring was made by the use of cable tool, auger, or air rotary methods and without the use of drilling fluid (mud and/or water), only the five volumes need to be minimally removed. Should recharge be so slow that the required volume cannot be removed in 48 consecutive hours, or the water remains discolored or excess sediment remains after the five volume removal, the authorized EM representative shall be contacted for guidance.

2. For those wells where the boring was made or enlarged (totally or partially) with the use of drilling fluid (mud and/or water), the contractor shall remove 5 times the measured amount of total fluids lost while drilling plus 5 times the standing water volume as above. The same procedure applies here as above with respect to slow recharge, discoloration, and sediment thickness.

3. In some instances, water may be added to a well as part of development once the initial seal is placed. Addition of water will depend on site/well requirements. The type and amount of water added shall have prior approval of the Contracting Officer or designated representative. When a bore, made with or without the use of drilling fluid, contains an excessively thick, particulate-laden fluid which would preclude or practically hinder well installation, the contractor may purge or dilute this fluid with clean water from the approved source. A record of purging fluid losses shall be made on the Well/Boring Record (Data Item # A051).

4. No dispersing agents, acids, disinfectants, or other additives shall be used during development or at any other time introduced to the well.

5. Well development shall be completed by the contractor at least 3 consecutive days before well sampling.

6. During development, water shall be removed throughout the entire water column by periodically lowering and raising the pump intake (or bailer stopping point).

7. For each well, a one-pint sample of the last water to be removed during development shall be obtained and kept on-site for visual inspection in an area where they will not freeze.

8. Contaminated water from bore holes and monitoring wells shall be containerized for proper disposal per the installation requirements.

9. Part of well development shall be the washing of the entire well cap and the interior of the well casing above the water table using only water from that well. The result of this operation shall be a well casing free from extraneous materials (grout, bentonite, sand, etc) inside the riser, well cap, and block casing between the top of the well casing and the water table. This washing shall be conducted before and/or during development, not after development.

12.18.5 The following data shall be recorded as part of development in the Well/Borehole Record (Data Item A051):

a. Well designation.
b. Date(s) of well installation.
c. Date(s) and time of well development.
d. Static water level from top of well casing before and 24 consecutive hours after development.
e. Quantity of mud/water lost:
   i) During drilling.
   ii) During fluid purging.
f. Quantity of fluid in well prior to development:
   i) Standing in well.
   ii) Contained in saturated annulus (assume 30% porosity).
g. Field measurement of pH before, twice during, and after development using an electrometric device (EPA 150.1 Methods for Chemical Analysis of Water and Wastes, EPA 600/479-020).
h. Field measurement of specific conductance before, twice during, and after development using conductivity meter (EPA 120.1 - Methods for Chemical Analysis of Water and Wastes, EPA 600/4 - 79-020). Obtain conductance and pH readings concurrently.
i. Depth from top of well casing to bottom of well (from diagram).
j. Screen length (from diagram).
k. Depth from top of well casing to top of sediment inside well, before and after development.
l. Physical characteristic of removed water, to include changes during development in clarity, color,

particulates, and odor.

m. Type and size/capacity of pump and/or bailer used.
n. Description of surge technique, if used.
o. Height of well casing above ground surface.
p. Quantity of fluid/water removed and time for removal (present both incremental and total values).
q. Name and phone number of approving State or Federal EPA representative.

12.18.6 Water removed from the well for development shall not be counted toward the volumetric removal requirements of any pre-sample purging.

12.19 Well Acceptance Criteria

12.19.1 General: Wells shall be approved by the Contracting Officer. Well approval shall be on a case-by-case basis. The following criteria shall be used in the evaluation process. Wells not meeting these criteria are subject to rejection.

a. The well and backfill shall meet the construction specifications in this SOW and the placement specifications listed in the Delivery Order.
b. Wells/bore holes shall not contain uncovered portions of drill casing or augers.
c. All well casing and screen materials shall be free of any unsecured couplings, ruptures or other physical breakage/defects before and after installation.
d. The annular material surrounding each installed well shall form a continuous and uniform structure, free of any fractures or cracks.
e. Any casing or screen deformation or bending shall be minimal to the point of allowing the insertion and retrieval of the pump and/or bailer optimally designed for that size casing (e.g., a 4-inch pump in a 4-inch schedule 40, PVC casing is optimal; a 2-inch in a 4-inch casing is not optimal).
f. All joints shall be constructed to provide a straight, non-contracting, and water-tight fit.
g. Well backfill materials (e.g., filter pack, bentonite, and grout) shall form a continuous annular filling around the well casing.
h. Installed wells shall be free of foreign objects/ materials (tools, pumps, bailers, soils, grout,etc.).
i. At least 75 % of the well screen shall be below water at the time of measurement for those screen depths determined by the contractor.

12.20 Topographic Survey

12.20.1 Horizontal Control: Each boring and/or well

installed under this contract shall be topographically surveyed by a licensed surveyor to determine its map coordinates to within +/- .5 ft (+/- 15 centimeters) using a State Plane Lambert Coordinate System. Coordinates shall be reported in meters or feet using the 1983 North American Datum, Oklahoma North Zone; and in feet using the 1927 North American Datum, Oklahoma North Zone. The Contracting Officer or designated representative will provide a list of permanent monuments acceptable for establishing horizontal and vertical control.

12.20.2 Vertical Control: Elevations for the ground surface (not the top of the coarse gravel blanket) and the top of the well casing (not protective casing) for each bore/well site shall be surveyed by a licensed surveyor to within +/-0.01 foot (+/-3 millimeters) using the National Geodetic Vertical Datum of 1929.

12.20.3 Survey Field Data: Survey field data (as corrected), to include loop closure for survey accuracy, shall be submitted through EM to the Contracting Officer with the required submission. Closure shall be within the horizontal and vertical limits given above. This submission shall clearly list the coordinates (and system) and elevation (ground surface and/or top of well casing, as appropriate) for all borings, wells, and reference marks. All permanent and semipermanent reference marks used for horizontal and vertical control (bench marks, caps, plates, chiseled cuts, rail spikes, etc.) shall be described in terms of their name, character, and physical location.